HEADQUARTERS OF THE ASSOCIATION — TREMONT TEMPLE BUILDING, BOSTON.

NEW ENGLAND WATER WORKS ASSOCIATION.

ORGANIZED 1882.

VOL. XI. JUNE, 1897. NO. 4.

This Association, as a body, is not responsible for the statements or opinions of any of its members.

REMOVAL OF IRON FROM GROUND WATERS.

BY HARRY W. CLARK, CHEMIST, IN CHARGE OF THE LAWRENCE EXPERIMENT STATION.

[*Read Jan.* 13, 1897.]

The occurrence of iron in some of the ground waters of the State in such amounts as to be objectionable is known to most of you by hearsay, and to some of you by experience. The fact has been frequently referred to in the reports of the State Board of Health, and in the report for 1895 an account is given of some experiments made by Mr. Desmond FitzGerald and Dr. Drown in regard to the removal of iron from the Reading water supply.

It has been known for some time that when the iron is present in the water in the form of a bicarbonate, that it can, by aeration and sand filtration, be removed quite completely from the water. When, however, it is present as a sulphate or protoxide of iron, the problem of its removal becomes much more difficult. Thus, with the Reading water, with the iron present in the form of a sulphate, exposure to the air, or even forced aeration, had generally little or no effect upon the iron contents of the water. Most of the iron would remain in solution, and could not be removed by sand filtration. Filtration through marble chips removed the iron, but increased the hardness of the water very considerably.

During last August I was asked by Mr. Goodnough, the chief engineer of the State Board of Health, to begin the study of another

water supply of the State containing a very excessive and objectionable amount of iron,— that of the town of Provincetown. This supply is taken from a system of tubular wells located about three fourths of a mile north of the centre of the village. The wells are five inches in diameter, average about twenty-eight feet in depth, and are sunk in loose sand, which contains more or less organic matter and iron. The wells were completed during the latter part of 1893. The amount of iron in the water has increased each year, being 0.1340 parts per 100,000 during 1893, 0.2212 during 1894, 0.3764 during 1895, and 0.4950 during that portion of 1896 in which my investigations were carried on at the Lawrence Experiment Station.

The removal of the iron by means of aeration and sand filtration was first studied. A small filter, containing four feet in depth of sand, was constructed, and the Provincetown water, having first been aerated by drawing a current of air through it, was applied to this filter at a rate of 1,000,000 gallons per acre daily. The filter was kept in operation for several weeks, and, as an average, 20 per cent of the iron was removed from the water.

Long continued aeration of the water did not affect or change the character of the iron in solution in it, and the filter was fully as effective when the water was applied to it without preliminary aeration. Reducing the rate of filtration to 100,000 gallons per acre daily, resulted in a removal of 80 per cent of the iron, but enough remained in solution to render the water turbid. Continuing the investigation, I found that the addition of an iron salt, such as ferric chloride or ferrous sulphate, caused a precipitation of a considerable portion of the iron in solution.

I also found that by passing the water through a filter composed of small pieces of iron, such as iron filings and turnings, that the ferrous hydrate formed by the water and iron-filtering material would unite with and precipitate the iron in the water to a remarkable extent, and that the iron could then be almost completely removed by subsequent sand filtration. This process for removing the iron could without doubt be used practically upon a large scale, and is somewhat similar to the Andersen process, where the water is shaken in iron revolvers with metallic iron, and the ferric hydrate formed, coagulates and precipitates the organic matter in the water. I have never heard of this process being used, however, for the purpose of removing iron.

Knowing the value of coke as a filtering medum, and knowing also, from experiments with it for a different purpose, that the small percentage of iron contained in it sometimes achieved remarkable results, a small filter containing 3.5 feet of coke breeze (the screenings from commercial coke), was put in operation Oct. 6. This filter was operated at a rate of 500,000 gallons per acre daily at first, and afterwards at the rate of 1,000,000 gallons per acre daily, and at both rates 98 per cent of the iron was removed from the water. The filter was continued in operation for several months, and the effluent was always clear, practically colorless, and the very small amount of iron in it remained in solution.

The coke in this filter was obtained from the Lawrence gas works, and additional filters operated for shorter periods, and containing coke from different gas works, and also metallurgical coke, gave equally good results.

Wishing to test the efficiency of this method upon a larger scale, a filter was constructed at Provincetown, 13.7 feet in diameter, that is, $\frac{1}{300}$ of an acre in area, and containing 3.5 feet in depth of coke breeze. This filter has been in operation for about three weeks, and for most of that period at a rate of 1,000,000 gallons per acre daily, and has removed 93 per cent of the iron of the applied water, as shown by the samples collected.

This result is not quite equal to that obtained upon a smaller scale at the experiment station, and is due to three causes: shallower depth of filtering material, poor distribution of the applied water (causing at times high rates of filtration through a small portion of the filter), and lower temperature.

The distributing apparatus has been improved during the past few days, and better work is expected. As for temperature, it is quite evident that the iron remains in solution better in winter than in summer. The water drawn from the taps in Provincetown in winter being much less turbid and not so highly colored as in summer, although containing fully as much iron. If allowed to stand in a warm room, however, the water soon becomes much more highly colored; but only a very slight separation and settling out of iron takes place during any season of the year, and gallon bottles of the water have stood in my laboratory week after week without change.

In regard to the action of the coke filters in removing iron, and their great efficiency as compared with sand filters, it can be said that

besides the mechanical actions of the very porous and rough particles of coke, which undoubtedly cause the removal of a large percentage of iron, its almost complete transformation into a body easily filtered out I consider to be due to a chemical action caused by the metallic iron in the coke. By means of this iron, just as by the iron filings in the filter previously described, the formation of ferrous hydrate is initiated, and this, during its formation, perhaps, acts upon the iron in solution in the water, changing it to ferrous and then to ferric hydrate, and in this form it is easily filtered out.

In conclusion, I would say that the use of coke in the purification of iron-bearing waters is not new, but whenever used previously has been largely if not entirely simply as a medium through which to pass the water for purposes of aeration, the removal of iron being subsequently accomplished by sand filtration, coarse coke being used in these instances instead of the fine breeze, such as I have used.

DISCUSSION.

Mr. HAZEN. I am very sorry that Mr. Bettes, the engineer and superintendent of the Queen's County Water Company of Far Rockaway, Long Island, is not here, because I was very anxious to have him tell you of the results that have been accomplished in taking the iron out of their water supply.

Mr. Clark has certainly done us a great service in showing the nature of the action of coke in removing iron from ground waters. Coke has been used, as Mr. Clark says, in nearly all of the German plants for removing iron, but I do not think that the chemical actions taking place have ever previously been pointed out.

This question of the removal of iron from ground waters is quite new in the United States. In Northern Europe it has been a live question for many years. Through the northern part of Germany, which is very flat and sandy, and also in the dunes of Holland, ground water is obtained freely and of most excellent quality in all respects except that it very often contains iron. Formerly this fact often led to the rejection of ground water supplies and the use of filtered river waters; but in recent years the great progress that has been made in removing iron has resulted in the use of these waters by many large municipalities.

A word in regard to the source and condition of the iron may be of interest to some of the members not familiar with it. Nearly all sand and soil contains iron in very considerable quantity. When water stands in, or passes through these materials, as long as free oxygen is present the iron remains in a ferric condition and is then entirely insoluble, and the water drawn from such strata is free from iron, nothwithstanding the fact that it has been in contact with large quantities of that substance. If, however, for any reason the supply of oxygen becomes exhausted in the ground, the organic matters often present in the soil or in the water reduce some of the iron in the ground to the ferrous state; that is, some of the oxygen in combination with the iron is taken away by the organic matters, which become partially oxidized by the process. The iron in the reduced or ferrous state is quite soluble in waters containing a little carbonic acid, as most ground waters do, and under these conditions the water drawn from such strata contains iron in solution, usually in the form of ferrous carbonate.

The solution of iron depends upon the existence or absence of the oxygen in the ground. Iron is almost always present in any material from which water supplies are drawn in sufficient quantity if dissolved to render the water passing through objectionable from iron for long periods, probably for centuries; and the trouble arises not from the presence of this iron in the ground, but from the conditions in the ground and in the water favorable for the solution of the iron.

This iron is objectionable in a water supply from its taste, and from its astringent action upon the system; from its disagreeable appearance, as it slowly precipitates out, discoloring the water; and from the fact that when used in the laundry it has a strong tendency to separate in the fibre of cloths, coloring them a dirty yellow brown, and when once colored, there is apparently no way of getting it out of the fibre: the color is as durable as the cloth itself.

The methods of removing the iron usually followed are very simple, and are exactly the reverse of the conditions which result in the solution of the iron in the ground. The water is brought in contact with an excess of air to oxidize the soluble ferrous iron up to the insoluble ferric form, which is then readily separated. The iron does not combine with the air at once when it is brought in contact with it, and although it will eventually all be oxidized, it is nevertheless possible to thoroughly aerate ground water and to keep it aerated for some

hours without oxidizing any appreciable amount of the iron. The presence of some other substance not in itself taking part in the reaction is apparently necessary to cause a prompt oxidation of the iron. Such a substance is furnished in the German works by the coke in the coke towers, which at once aerate and cause the oxidation of the iron. In other cases the surface of the sand in the filter answers this purpose; and I have found by some experiments during the past year that in some cases this oxidation on the surface of the filter is almost instantaneous. The water above the filtering material contained plenty of oxygen in solution, but all of the iron was in solution in the ferrous state, no oxidation having taken place. Immediately after entering the filtering material the iron had all been removed as ferric hydrate, and only the slightest trace of iron remained in solution.

The waters which Mr. Clark has mentioned seem to be peculiar, in that the iron is present, in part at least, in the form of ferric sulphate or at least as a compound more stable than the carbonate, and cannot be removed with the readiness with which it can be when in the form of a carbonate. This condition of affairs has not, so far as I know, been encountered in any of the foreign works; and we shall await with much interest developments as to how common it is likely to be in this country.

Some of the largest and most interesting works for the removal of iron are those at Kiel, at Charlottenburg and at Leipzig in Germany, and at Hague and Amsterdam in Holland. In the older Dutch plants the water was simply aerated and then filtered through sand. In the German plants the water was passed through coke very rapidly, many times as rapidly as in Mr. Clark's experiments, and it was found in this way that the water was aerated and the iron was largely oxidized and partially removed; but to take out the remainder of the iron and render the water bright and clear, it is necessary to afterwards pass it through sand at rates from five to ten times as great as are employed in ordinary sand filtration.

At Far Rockaway the coke tower was dispensed with, and it was decided to try the sand filters alone as an experiment, and it was found that they removed all of the iron, and no further treatment was necessary. The rate of filtration was only somewhat greater than that followed in the filtration of surface waters, because it was desired to use at times the water from certain brooks, and it was thought best

to use a rate of filtration which would be adapted to the purification of these waters as well as to the removal of iron.

Mr. HAWES. I would like to ask Mr. Clark if there was any examination made of the ground water in the vicinity of the pipe wells, but outside of the system of wells and distribution piping, for the purpose of ascertaining what changes may have taken place in the condition of the water in the ground.

Mr. CLARK. I cannot answer that very completely, but I think that the water was examined in a number of places outside of this system. That was in 1893, and I had nothing to do with it then. I think Mr. Johnson can tell you about that.

Mr. HAWES. My reason for asking the question was because of the peculiar conditions at Provincetown. There has always been a question in my mind as to the effect upon the water in the ground when there has been a draft upon the supply by means of the wells, whether or not the water would deteriorate or improve. Quite recently test wells have been put down near the station, as I understand from the superintendent, and water pumped from them. At places where, during the preliminary investigations in 1892, water with considerable color and odor was obtained, at this time the water was found to be improved. It is in the vicinity of the large wells, and of course the improvement was only noticed by observation and not by chemical analysis, the water appearing colorless and free from odor.

I am desirous of knowing if the increase in the quantity of iron, as ascertained by chemical analysis, was in the water taken from the works, or from the ground, or both, so as to show whether or not the additional quantity of iron was in any way due to the system itself; that is, if the metallic iron of the pipes or standpipe in any way contributed to the quantity.

Mr. CLARK. The water analyzed just as pumped shows an increase of iron almost every month, year after year,—a slight increase. Certainly that cannot be due to any part of the system except the wells themselves. There is no increase as it goes from the pumping station to the houses. I had, during the fall, samples from three parts of the system, (1) the pumping house, (2) as it comes from the standpipe, and (3) the taps in the town; and the iron averages just about the same. That is, one week you might get it a little more from the town than the well, and another week you would not, so the average of the three places would be about the same.

A MEMBER. Have I understood Mr. Clark rightly that iron in the form of sulphate was not removed by sand filtration, and then later the addition of the sulphate caused removal? I did not get that clear.

Mr. CLARK. Iron in the form of sulphate, as is the case at Reading, cannot be removed by simple aeration and filtration. But if we have water with iron in a different form, as in Provincetown, and add the ferrous sulphate to it we get ferric hydrate in the water, which will precipitate and then can be filtered out.

A MEMBER. I would like to know if the filtration used at Reading was intermittent filtration.

Mr. CLARK. I think it was operated intermittently at times, and at times continuously. With the Provincetown water, as I said, — and I think the same thing can be said in regard to the Reading water, — running the filter at as low a rate as 60,000 gallons resulted in a removal of from 80 to 90 per cent of iron; but the idea is, if you can, to run the filter at a higher rate.

THE WATER SUPPLY OF PROVINCETOWN, MASS.

BY LOUIS E. HAWES, C. E., BOSTON, MASS.

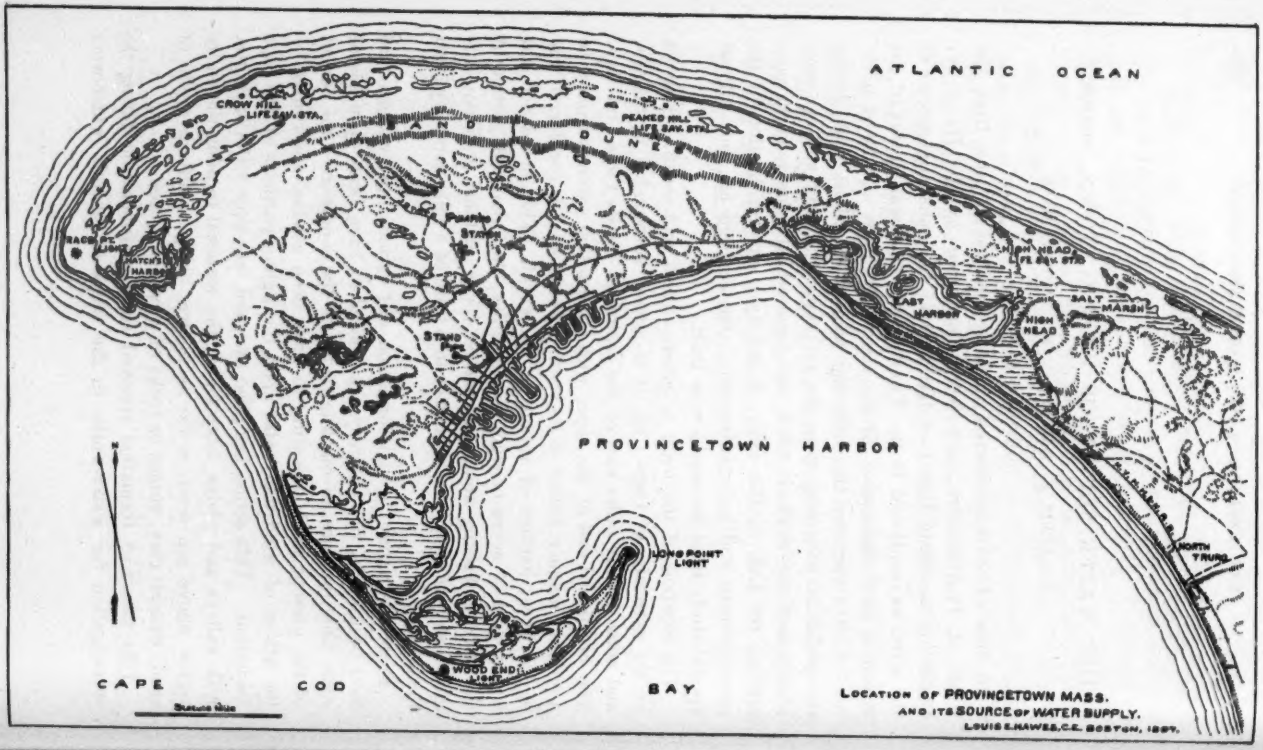
[*Read Feb.* 10, 1897.]

In view of the experiments upon the removal of iron from the water at Provincetown, now being conducted by Mr. Harry W. Clark for the State Board of Health, and the unusual character of the water as mentioned in the Twenty-fourth Annual Report of the Board, a brief description of the source of supply may be of interest. I have prepared the following from observations made during the preliminary investigations for the supply in 1892 and the construction of the works in 1893, and have added a few remarks concerning the iron in the water, based upon my recollection of the circumstances and information which has reached me, but without special study since the works were built.

The location of the town is practically in mid-ocean. Situated on the extremity of Cape Cod, it is almost surrounded by the sea, and some twenty miles east of the mainland across Cape Cod Bay. The broadened end of the cape, with an arm that extends from it in a peculiar manner, forms on its southerly side what is considered one of the finest harbors of refuge in the world. This broadened end has an area of seven or eight square miles, the inhabited portion of the town extending along the harbor for a distance of about two miles east and west, and a quarter to a third of a mile northerly from the shore.

From the nature of the formation and various observations that have been made, this territory is supposed to have been open sea at some time previous to our knowledge of the conditions; the advent of the present land appearing to have been gradual and caused by the action of wind and water upon the lighter particles of the cape formation. This action has piled the sand into huge drifts or ridges, with valleys and plains intervening, the material forming the entire region above sea level, as far as known, being a uniform grade of sand, without clay, stones or rocks of any description.

This theory of formation received some corroboration during the investigation for water-works in the shape of smooth, water-worn


ATLANTIC OCEAN
CROW HILL LIFE SAV. STA.
PEAKED HILL LIFE SAV. STA.
PROVINCETOWN HARBOR
LONG POINT LIGHT
WOOD END LIGHT
CAPE COD BAY
LOCATION OF PROVINCETOWN MASS. AND ITS SOURCE OF WATER SUPPLY.
LOUIS E. HAWES, C.E. BOSTON, 1897.

beach stones, which were taken from a well at about the depth of low tide, and situated a mile inland, indicating wave action at some remote time in that locality; also from the fact that in driving pipes through the loose sand, the backbone or compact material underlying the territory was invariably reached at a somewhat uniform depth below mean sea level, the loose sand above varying but little in its physical appearance.

At the narrow neck connecting the broad end with the rest of the cape is a shallow body of water called East Harbor, which has been enclosed or separated from the large harbor by a dike and the railroad constructed across it. Although its water was formerly salt, it has now become fresh, the transition having been gradually effected in nature's laboratory through the agencies of evaporation, rainfall, and the movement of the tides. As high tides have been known to sweep entirely over the narrow land separating East Harbor from the Atlantic Ocean, it is not at all improbable that the present end of the cape may have been an island at some period in its existence. From East Harbor, southerly, beginning at what is called High Head in the town of Truro, where the formation changes abruptly, the material is in accordance with the more usual New England formation, appearing, however, to be mainly sand and gravel.

At Provincetown the surface is covered with vegetation and well wooded in places, except on the Atlantic Ocean side of the cape, where the moving of the sand with every wind storm is still in progress, burying what little vegetation has secured a foothold and occasionally covering sizable trees, leaving only their tops visible.

The scene is well worth a special trip to the "Backside," as this part of the cape is called in Provincetown, and the locality is annually visited by many; the new State road through the Province Lands to the Sand Dunes making the region more accessible than formerly.

During the process of formation, organic matter of marine origin below sea level, and surface vegetation above, have doubtless been covered by the shifting sand, and slowly decomposing since, now impart color and odor to the ground water where such matter was located. As suggested by the appearance of marine growths observable on the harbor bottom in shallow water, and the varied quality of the ground water within short distances, it is probable that the organic matter occurs in irregular patches and with no uniformity of distribution.

Aside from the water in the ground, — which is in abundant quantity and nearly level from sea to sea at about the elevation of high tide, and which, if the theory of formation mentioned is correct, has replaced the salt water formerly there, — and a few very shallow ponds of stagnant water, no important body of fresh water is within reach of Provincetown for its water supply. Consequently there was no option but to secure a ground water source.

In determining the best place from which to take the water, some forty-five test wells were driven in various places through the loose sand. The effect of decomposed organic matter was frequently apparent in the water found, and occasionally, when present in large quantities not completely decomposed, could be seen by the naked eye as minute brown or black particles having organic characteristics. Hence it became a problem of finding the greatest area within which the water was of the best quality. This was determined to be at the present location of the pumping plant, which is situated in a valley or plain about three fourths of a mile inland from the village, the water at this place being more uniformly good than elsewhere, free from the contaminating influences of habitations, sufficiently distant from the sea to preclude the possibility of in time drawing in salt water, and much softer than the well water in town, which was found to be in most cases seriously affected by house drainage or sea water.

The water, when pumped by hand from each of the six five-inch pipe wells of the system as put down, was clear, tasteless, and odorless. When pumped from all the wells collectively in large quantities, the water had a higher degree of color, comparatively speaking a little less than the Sudbury River water, and a slight odor of sulphuretted hydrogen, the latter quickly disappearing on exposure to the atmosphere.

The extreme porosity of the sand, permitting a free movement of the water through it, and the adaptability of the type of strainer used on the wells was demonstrated by pumping from a single well at the rate of two hundred and fifty gallons a minute.

Examinations for iron in the water, made at the time of a preliminary pumping trial (the quantity of iron in the earlier samples not having been determined), showed that the quantity found in the water after passing through the temporary pump and uncoated wrought-iron suction pipe was about twice as much as was found in water from the same well drawn directly from its top; and about

twenty-three times as much as was found in water taken from an observation well of 1¼-inch galvanized pipe in the same vicinity, the latter quantity being below the amount necessary for precipitation. The results of these examinations left a question as to how much influence, if any, the temporary uncoated suction pipe had on the quantity of iron found.

In consequence of the excellent filtering properties of the Provincetown sand, an idea was entertained that it might in time act in a beneficial manner in the vicinity of the wells, after long-continued pumping had removed a large quantity of water and created a better circulation. The existing conditions are such that the only natural movement of the ground water is when it runs out on the beach at low tide, giving the upper layers an opportunity to move first and most rapidly, while the lower layers have little or no opportunity to move from this cause, rendering them therefore somewhat stagnant.

That some beneficial action has taken place in the sand in the vicinity of the wells would seem to be indicated by the fact that from all of a number of test wells put down in 1895 under the direction of Mr. J. D. Adams, Superintendent and member of the Water Board, the water was reported to be good; that is, free from color, taste, and odor. One of these wells was sunk at the known location of a test well in 1892, from which water with both color and odor was obtained.

The possibility of applying artificial filtration to the water at some future time was considered when the works were built, but filtration was not deemed essential until the necessity became apparent.

During construction of the works especial care was taken throughout the entire system to protect the pipe coatings, and in asphalting cut ends as a precautionary measure; for with ordinary water, rust and tuberculation begin only too soon in spite of coatings. The high normal chlorine of this water, due to the location, and the presence of sulphuretted hydrogen, rendered the possibility of its having a special affinity for iron not at all improbable.

It is of interest to note that there was a marked falling off in the quantity of iron found in the water when the permanent works were put in operation, the yearly average up to 1896 not having reached the average obtained from samples taken during one month's pumping in 1892 with the temporary pump and suction pipe.

The possibility of concentration or sedimentation contributing to the increased effect of the iron in its laundry action suggests itself,

for there is ample opportunity for this to occur in the pipes at places where the water has a diminished velocity, not only in the mains and hydrant branches, but in the suction pipe between the wells and pump, where there is also some opportunity for oxidation to take place.

The Provincetown works were designed so that the water should be aerated by permitting it to pass through the atmosphere in a thin spray at the standpipe, which has a capacity of 460,000 gallons, before passing to consumers; primarily, for the purpose of removing any undesirable gas that might be present, but also with the idea of assisting oxidation of the iron in the water at a place where the sediment, if any, could be removed periodically. The occurrence of sedimentation was shown later by a sample taken at the bottom of the tank when being cleaned.

That the passage of the water through the reservoir where the conversion of the iron from the soluble to the insoluble form is assisted by aeration, had some effect in a practical way, would appear from the fact that for nearly two years the water was used satisfactorily in the large laundries in town, the proprietor of one in particular expressing a decided preference for it on account of its softness. At the end of this time, and while pumping direct to consumers during the cleaning of the tank, favorable comments concerning the lighter color of the water led to a continuance of the direct pumping for a period of ten days, which seems to have given a different effect in the laundries, as the first complaints from them were received at that time.

In this connection it may be mentioned that parties using the water for washing purposes state that during the process, the coloring matter imparted by the iron appears to lie upon the surface of the cloth in the form of sediment, giving white clothes a yellow or streaked look, which if noticed in season, can be easily removed by rubbing or rinsing.

Many interesting features concerning the ground water at Provincetown have been noticed. In a certain yard there are two wells not very far apart, from which two qualities of water are drawn; from one the water is preferred for culinary purposes, from the other the water is used almost exclusively for washing clothes.

In another case there are two wells driven in the sand beneath a house, only a few feet apart, but to different depths; one furnishes fresh water, and the other salt water.

DISCUSSION.

Mr. HAZEN. The suggestion is advanced by Mr. Hawes that the iron in the Provincetown water may be due wholly or in part to the action of the water on the iron of the well points, collecting pipes, force main, etc., instead of coming from the soil. This idea naturally suggests itself, and while I am not personally familiar with the conditions at Provincetown, I am certain that this is not ordinarily the explanation of iron in ground water. When iron rusts in contact with water, the ordinary product is ferric hydrate, or, as it is commonly called, iron rust. This substance is insoluble in water. If it is carried in suspension it is at once apparent, and its appearance and results are in every way entirely different from those of the ferrous compounds found in solution in ground waters, and which are so objectionable. Mr. Hawes also mentions that particular care was used in constructing the system to completely coat the iron at every point so that the water could not come in contact with the metallic iron.

The conditions at Provincetown, as Mr. Hawes has described them, are very similiar to the conditions of the dunes of Holland. These dunes were originally almost, if not quite, islands; but the land back from them has been reclaimed by the construction of dikes along the rivers, while along the sea the dunes themselves serve to keep the ocean back. The poulders thus formed are often ten, twenty, and in some cases thirty feet lower than the level of the ocean, and are now cultivated.

The cities of Amsterdam, Haarlem, Leiden, and Hague are dependent upon ground water drawn from these dunes for their supplies. Unlike Provincetown, the water is collected in galleries constructed entirely of masonry or tiles, or in open canals, no iron whatever entering into their construction. Notwithstanding the method of collection, the water contains iron in large quantity, and would be just as troublesome as it actually is at Provincetown if it were used without treatment. As it is, this water is aerated and afterwards filtered through sand filters, of the ordinary construction, which remove every trace of the iron, and the water supplied is as good and pure as is supplied to any large city. At Columbus, Ohio, also, a collecting gallery is used, constructed entirely of masonry, but the

water drawn from it contains iron in solution in large quantity. Cases of this kind, I am sure, could be multiplied if search was made for them; and so while it may possibly happen that a water may exist which in itself has a tendency to dissolve metallic iron, and that such a water may take a little additional iron from the pipes through which it passes, I cannot believe that this is ever a leading or even important factor in causing the trouble experienced from iron in ground waters.

Mr. HAWES. The possibility of metallic iron from the pipes contributing to the quantity of iron found in the water is a question of much interest, and specific data which will aid in its determinination are valuable.

The promulgation of the idea should not, however, be credited to me, as it originated with another, and in connection with the Provincetown water, simply as a suggestion, but coming from excellent authority in matters pertaining to water analyses, is entitled to consideration.

In consequence of the absence of conclusive demonstration I have neither accepted nor rejected it, but have stated some facts which have a bearing in this particular case, for the purpose of affording as much light as possible upon what has remained a doubtful point.

It would, of course, be gratifying to know positively that the iron of the works had no influence upon the quantity found in water of this peculiar character. Mr. Clark states in his paper on the removal of iron from ground water, that the metallic iron of the coke and iron filings performed an important function in the process of filtering this water, which would indicate that the water has an affinity for metallic iron to a marked degree.

In comparing the quantity of iron in ground waters obtained from pipe wells with the quantity obtained from works supplied by masonry galleries, as a way of determining the question, the necessary knowledge of the connecting pipes, and places from which the samples are taken should not be overlooked, for otherwise such a comparison is not conclusive from either point of view. Samples taken, as in the majority of cases, from a faucet in the pumping station may have been in contact with the iron of the suction pipe, vacuum, pump, and air chambers and connecting pipes, which ordinarily exist with either mode of supply.

The works of Reading, Mass., may be cited as a single illustra-

tion: the supply is from a collecting gallery constructed entirely of masonry, but the water is obtained by the pump through 450 feet of iron suction pipe.

The all important question, in this case at least, is evidently, as to why the quantity of iron increases from year to year; for if the water can be used in the laundry satisfactorily until it attains a certain quantity of iron, the problem is one of keeping the quantity below that degree.

The removal of a large part or the whole by filtration offers a ready solution, but the determination of the controlling reasons for the increase in quantity and changes before and after the water enters the works, I believe to be of interest and value in arriving at an understanding of the true situation and applying a remedy.

In comparing results of analyses of the Provincetown water made in 1894 and published in the report of the Massachusetts State Board of Health for that year, which are the only ones available that show the amount of iron in samples collected the same day, one before and the other after the water had been aerated in its passage through the standpipe, and extending over any considerable period of time, it is noticed that on six out of the eight days when samples were taken simultaneously, the quantity of iron found in the water that had passed through the tank was less than was found in the samples collected at the pumping station, as follows: —

IRON, PARTS PER 100,000.

	Water from tap at Pumping Station.	Water from a faucet in town.
1894, April 10	.1300	.1100
" May 8	.0950	.1050
" June 12	.2340	.2000
" July 16	.3100	.3900
" Aug. 14	.2500	.1500
" Sept. 10	.2400	.2000
" Oct. 9	.3600	.2500
" Nov. 8	.4300	.2500
Average	.2561	.2069

During this time the water was being used in the large laundries in town, and no difficulty was mentioned by the proprietors until the following year.

THE IRON-REMOVAL PLANT AT READING, MASS.

BY LEWIS M. BANCROFT, SUPERINTENDENT.

The water-works of Reading were completed in 1891, with the late M. M. Tidd as engineer.

Water is pumped from a filter gallery near the Ipswich River, about three miles north of the village, to a covered standpipe, 30 feet in diameter and 100 feet high. The bottom of the gallery is 22 feet below the level of the meadow. The gallery is 2½ feet wide and 4 feet high inside, L-shaped, with a total length of about 240 feet. The walls are of rough field stone, like an ordinary culvert, under a street; the top is covered with flat stone laid in cement. About 75 feet of the gallery is parallel with and about 40 feet from the river; the remaining 165 feet extends away from the river at a right angle. The quantity of water obtained has been quite satisfactory, but the quality has not.

After the works had been in operation about three months, complaints of the taste and odor of the water were very frequent, also of the staining of white clothes when boiled in it. This was at first laid to the new pipes and the new paint on the inside of the standpipe, as the first complaints were heard soon after the standpipe had been painted inside. After emptying the standpipe and flushing the pipes, it was found that the cause of trouble must be looked for elsewhere. The State Board of Health in their report for 1891 state that the water contains iron in solution, which precipitates out as a reddish brown deposit on exposure to the air. Waters of this character often have a disagreeable odor, from carburetted and sulphuretted hydrogen. The amount of metallic iron in a sample taken Nov. 8, 1891, was 1.33 parts in 100,000, or 0.78 grains per gallon. In December, 1894, a sample contained 1.03 parts in 100,000. During the last four years the amount of iron has averaged as follows: 1893, 0.1251; 1894, 0.2942; 1895, 0.2275; 1896, 0.2475 parts in 100,000.

In February, 1893, Mr. Desmond FitzGerald, C. E., was engaged to investigate and devise some plan for removing the iron from the water. He made a very thorough and careful investigation, and made his report in February, 1894, with the following recommendations: —

First. Pump the water from the filter gallery into a covered reservoir built in two sections, each of which should hold 500,000 gallons.

Second. Aerate the water thoroughly on its way to this reservoir.

Third. Build invert to the reservoir with a steep inclination towards the drains, so that the sediment precipitated upon the bottom will scour out easily.

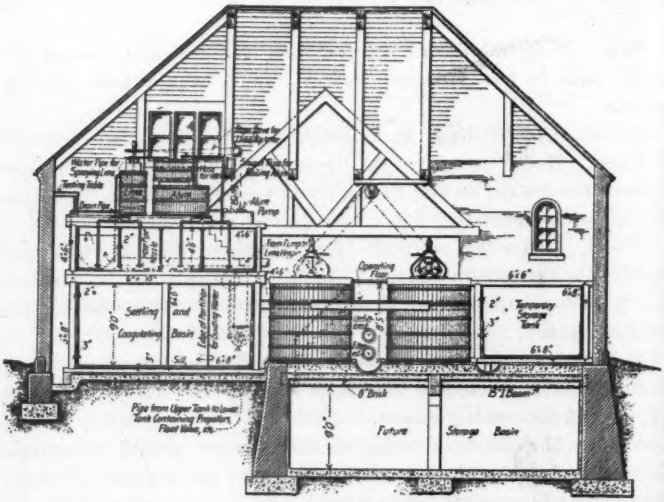
Fourth. Place this reservoir high enough to filter the water and return it to the present pumps. The water drawn from this reservoir can be filtered rapidly through any cheap form of filter which can be readily cleaned.

Fifth. After the plans are made, I should recommend you to put in the filters at once, and run them without the reservoir until the opening of the coming season.

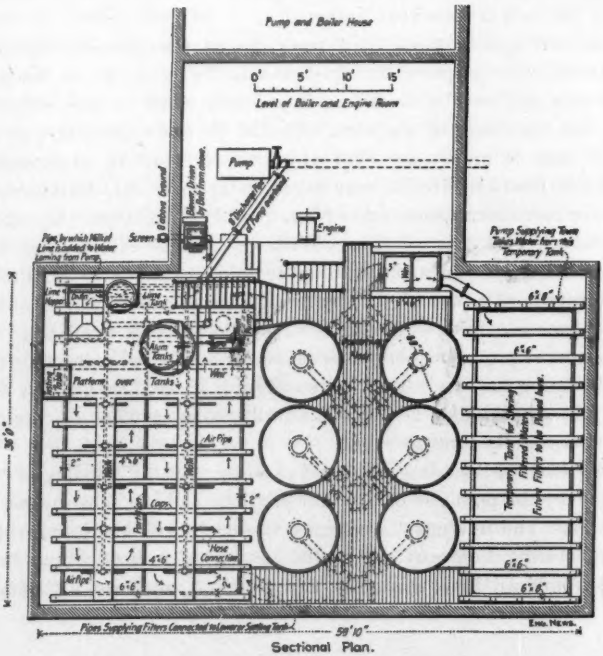
Sixth. The outlets or drains to the reservoir should be arranged so that the flocculent iron can be collected for use, if found necessary. I have found in my experiments, and it was suggested by Dr. Drown, that by adding some of this flocculent iron to the water, the precipitation of the iron is somewhat hastened.

Plans and specifications for a reservoir, as recommended by Mr. FitzGerald, were prepared by Mr. Frank L. Fuller, C. E., of Boston, and it was proposed by the Water Board to proceed at once with the work, but the voters of the town objected to the expenditure of so large a sum of money on what appeared to them an experiment. The State Board of Health were asked to approve Mr. FitzGerald's plans, or recommend some other plan. On Feb. 18, 1895, they made their report, with this advice: "With its present information, the Board advises the town of Reading to take measures to obtain its future supply as a part of the metropolitan water district, and abandon its present source when the new supply becomes available. In the meantime provisions should be made to improve the present supply by preventing the flooding of the meadow over the filter gallery, and it may be advisable to adopt, temporarily, some system of filtering the water rapidly through sand."

Early in 1895 measures were taken to prevent the flooding of the meadow by the purchase of the mill privilege and the construction of a low dike, and in August a contract was made with the Cumberland Manufacturing Company, of Boston, to put in a purification plant, which combined lime treatment, aeration, and rapid sand filtration,


Settling and Coagulating Basin
Temporary Storage Tank
Future Storage Basin
Pipe from Upper Tank to Lower Tank Containing Propellers, Float Valve, etc.

Transverse Section.



Sectional Plan.

FIGS. 2 AND 3.—PLAN AND SECTION OF WATER PURIFICATION PLANT, READING, MASS.

through mechanical filters of the Warren type. This company had been studying the water for three years.

The water is taken from the existing suction pipe by a low-duty, compound, duplex Worthington pump, 6 x 9 x 11½ x 10, and delivered into the aerating basin, which is 33 x 19 x 4½ feet. There is a hopper at one end through which the water is delivered. At this point it is met by the descending supply of milk of lime, which is supplied from a tank, on top of which is a pan in which the lime is slaked. On receiving the lime it passes into the aerating basin proper, which is so divided by partitions as to cause the water to travel back and forth four times. The water during this passage is aerated by means of 23 1¼-inch nozzles, perforated with 6 $\frac{1}{16}$-inch holes. Air for this aeration is supplied by a No. ½ Wilbraham Baker blower through a 5-inch pipe at a pressure of 2½ pounds per square inch, as shown by a mercury gauge. This blower has a capacity of 150 cubic feet of air per minute. The iron is thus thoroughly oxidized, and the water, together with the suspended iron, passes over the last weir and through a 10-inch pipe at the outlet of which is an 8-bladed propeller of brass, so arranged as to revolve freely with the passage of the water. This, by means of two small bevel gears and an upright shaft, operates an alum pump, consisting of six hollow arms radiating from a chambered hub and bent in the direction of rotation. This pump revolves in a small tank containing a dilute standard solution of alum, and by its revolution each arm takes up a small amount of alum water, passes it into the hub and to the deflector, which sends it down into the water. Only two of these tubes are used, the other four being closed up.

The water has now reached the settling and coagulating basin, which is 33 x 19 x 9 feet, and is beneath the aerating basin and provided with partitions. The water remains about an hour in this basin and from there passes to the filters, which are 6 tanks 8 feet 8 inches in diameter and 8 feet 5 inches deep, and each have an area of 54 square feet. Each filter contains a bed of sand from Sebago Lake, Me., 2 feet in depth, supported by a perforated copper bottom. The agitator for cleaning this bed consists of a heavy rake containing 11 teeth 25 inches long, rotated by a system of gearing and capable of being driven into the bed by means of a screw mechanism; the current of water being reversed and flowing up through the sand, the entire bed is thoroughly scoured. Power for running this agitator and the blower is furnished by a 10 horse-power upright Lawrence engine.

The main, collecting the filtered water from the various filters, passes along between them to a weir, over which the water is compelled to pass and which controls the operation of the filters. From this weir the water passes to a clear water tank, 31 x 10½ x 8 feet, and from this tank flows to the pumps which supply the town.

This tank occupies a space which is intended for more filters. A storage tank for filtered water, 32 x 34 x 9 feet, is provided for underneath the filters, but has not been finished.

The alum solution is prepared in two tanks, one above the other, on top of the aerating basin. The alum is placed in the upper tank, and, by means of water and steam admitted, a concentrated solution is made. A small portion of this is drawn off into the lower and larger tank and mixed with the water until a standard five per cent solution of alum is formed. This solution is then fed into the small rectangular box in which revolves the alum pump.

The building which contains this plant is of brick, with slate roof, and adjoins the pumping station. Owing to the changeable character of the water, a strict watch is kept upon it, the incoming water is tested for iron, and the water both before and after aeration and after coagulation is tested, both for alkilinity and iron, and after filtration is tested for iron, lime, and alum. The engineer in charge has no difficulty in making his tests, and so regulates the amount of lime and alum as to prevent the use of an excess and enable the plant to properly handle the water.

In July and August, when the consumption of water is large, the filters were washed twice a day; but when the consumption is light they are washed once a day. We have found by a careful test that about four per cent of the water pumped is required for washing the filters. We use pure lime made from marble, which is procured from northern Vermont. The plant has been in operation since the first of July, and samples of the water, both filtered and unfiltered, have been analyzed by the State Board of Health twice a month, and the least amount of iron removed was 83.16 per cent, and in two cases 100 per cent was removed. The average amount of lime used per gallon of water is three grains, and of alum one and a half grains.

I am of the opinion that had the large settling basins, as recommended by Mr. FitzGerald, been built, these filters could be run with the use of but very little or no coagulant. The piping of the filters is so arranged that these can be added at any time.

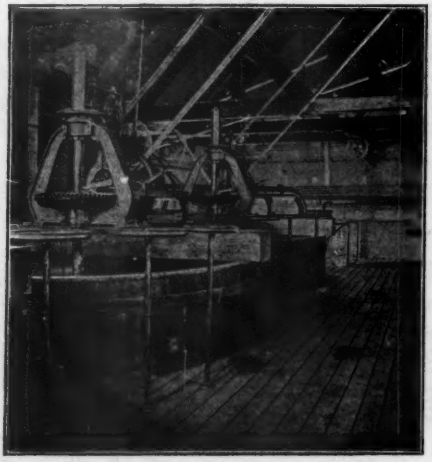
ANALYSES OF WATER FROM READING WATER-WORKS, MADE BY MASSACHUSETTS STATE BOARD OF HEALTH.

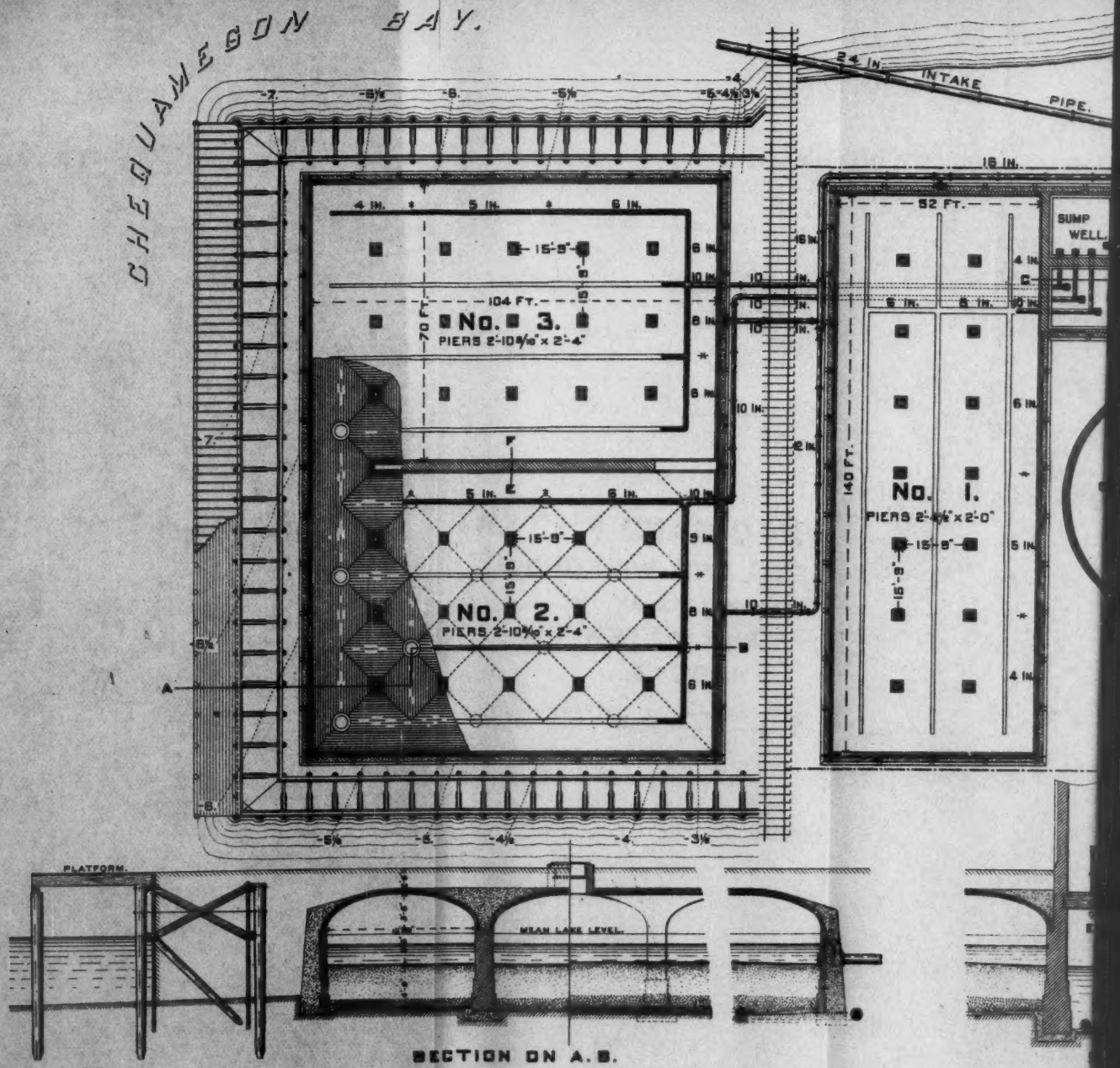
PARTS IN 100,000.

Date.	Appearance.			Residue on Evaporation.	Ammonia.		Chlorine.	Nitrogen as		Oxygen Consumed.	Hardness.	Iron.	Per cent of rem. of iron.	Remarks.
	Turbidity.	Sediment.	Color.		Free.	Albuminoid.		Nitrates.	Nitrites.					
July 27	Decided.	Cons. rusty.	Turbid 0.40	9.50	.0048	.0076	.53	.0050	.0000	.3420	3.6	.0850	–	Unfiltered.
" 27	None.	None.	0.13	15.50	.0058	.0056	.52	.0030	.0000	.1520	8.2	.0090	89.41	Filtered.
Aug. 10	Decided.	Considerable.	0.63	8.70	.0048	.0056	.54	.0000	.0001	.3635	2.6	.1400	–	Unfiltered.
" 10	Very slight.	None	0.30	14.50	.0040	.0046	–	.0000	.0602	.2410	7.9	.0210	85.00	Filtered.
" 25	Decided.	Considerable.	0.60	7.40	.0070	.0064	.56	.0000	0000	.3542	2.5	.0950	–	Unfiltered.
" 25	None.	Very slight.	0.20	14.20	.0044	.0056	.52	.0020	.0010	.2010	8.0	.0030	96.84	Filtered.
Sept. 8	Dist. from iron.	Cons. brown.	0.50	8.50	.0066	.0046	.62	.0030	.0030	.1725	2.6	.0950	–	Unfiltered.
" 8	None.	Very slight.	0.20	13.90	.0030	.0044	.61	.0030	.0018	.1725	7.3	.0160	83.16	Filtered.
" 21	Decided from iron.	Heavy rusty.	0.38	12.20	.0084	.0088	.56	.0050	.0000	.3160	3.9	.3350	–	Unfiltered.
" 21	None.	None.	0.10	18.00	.0048	.0062	.55	.0040	.0025	.2291	10.0	.0000	100.00	Filtered.
Oct. 6	Decided from iron.	Cons. rusty.	1.10	12.20	.0090	.0120	.56	.0030	.0001	.4068	4.0	.3800	–	Unfiltered.
" 6	Very slight.	None.	0.09	20.40	.0010	.0086	.57	.0030	.0035	.2923	11.3	.0100	97.37	Filtered.
" 21	Dec'd m'ky and rusty floc.	Heavy rusty.	After set. 0.10	14.90	.0104	.0106	.53	.0050	.0000	.4895	5.2	.5600	–	Unfiltered.
" 21	None.	None.	0.08	24.80	.0026	.0078	.57	.0050	.0060	.2409	15.5	.0000	100.00	Filtered.
Nov. 10	Decided.	Considerable.	Turbid 0.50	15.40	.0110	.0098	.55	.0050	.0000	.4758	5.8	5250	–	Unfiltered.
" 10	None.	None.	0.10	26.80	.0032	.0082	.54	.0050	.0015	.2457	14.7	.0360	93.14	Filtered.
" 24	Dec'd milky and floc.	Heavy rusty.	0.50	15.10	.0102	.0090	.57	.0080	.0001	4485	5.0	.4800	–	Unfiltered.
" 24	None.	None. [yellow.	0.12	24.60	.0022	.0082	.61	.0050	.0010	.2457	15.0	.0010	99.79	Filtered.
Dec. 8	Dec'd floc. of iron.	Heavy, light	After prc. 0.40	16.76	.0092	.0120	.48	.0070	.0001	.5694	6.3	.4450	–	Unfiltered.
" 8	None.	None.	0.10	20.60	.0016	.0078	.56	.0050	.0010	.2317	14.5	.0020	99.55	Filtered.
" 20	Dec'd milky and floc.	Cons. rusty.	0.50	15.00	.0104	.0092	.55	.0080	.0000	.4920	6.0	.4850	–	Unfiltered.
" 20	None.	None.	0.10	22.80	.0022	.0068	.57	.0100	.0010	.2400	13.5	.0050	98.97	Filtered.

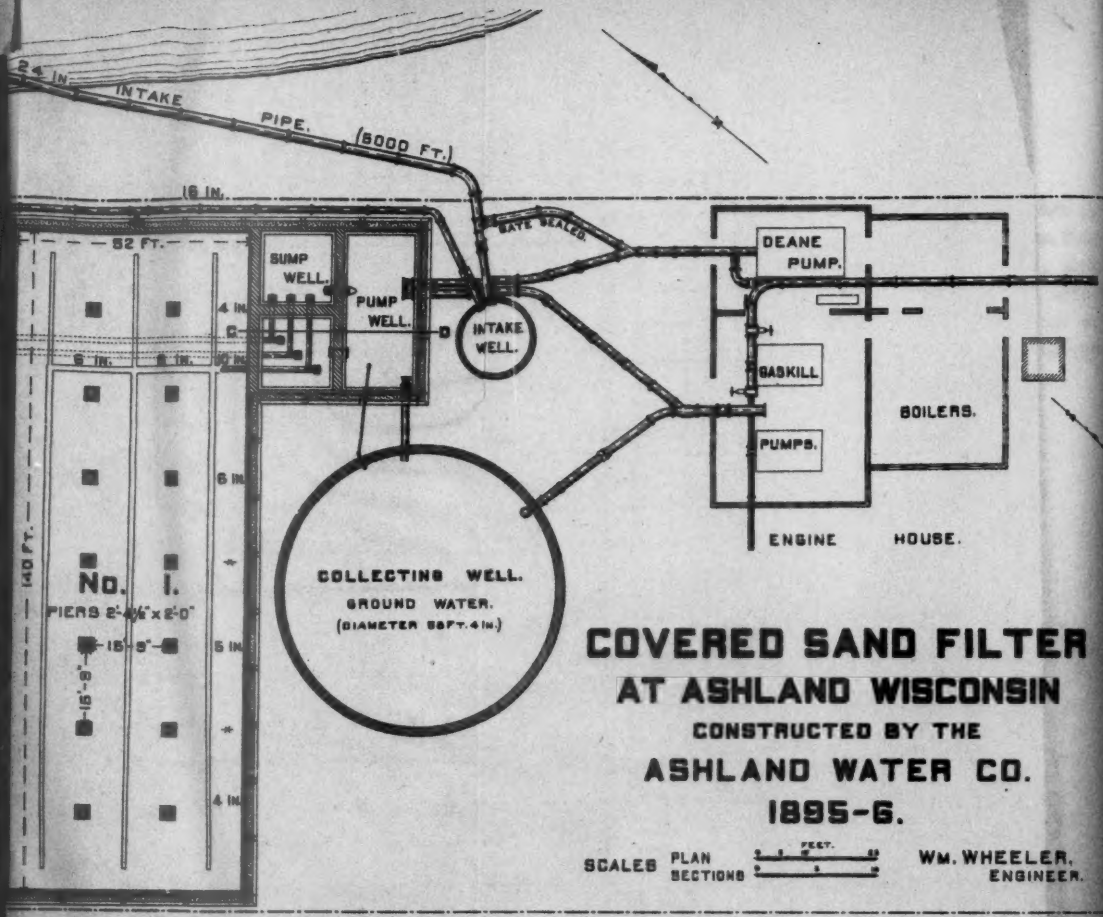
DISCUSSION.

Mr. Nye. It may be of interest to the members to know that in the course of the operation most of the lime, as well as the alum that is coagulated in contact with it, is caught in the settling basin; and I am informed by the engineer of the plant that at one time, after something like ten weeks' operation, there was about six feet of sludge in the bottom of the basin, which was removed and run off into the river. The average amount, I think, is about a foot.





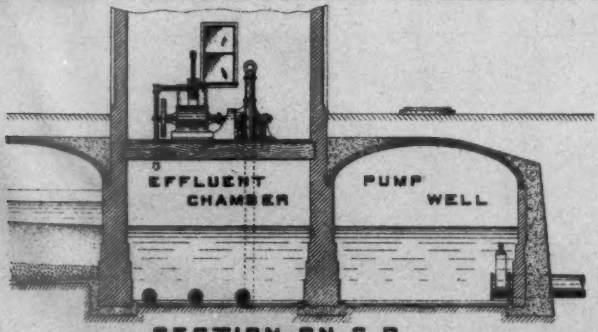
SECTION ON A. B.



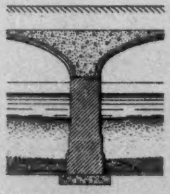
COVERED SAND FILTER
AT ASHLAND WISCONSIN
CONSTRUCTED BY THE
ASHLAND WATER CO.
1895-6.

SCALES PLAN SECTIONS FEET.

WM. WHEELER, ENGINEER.



SECTION ON C.D.



SECTION ON E.F.

COVERED SAND FILTER AT ASHLAND, WIS.

BY WILLIAM WHEELER, C. E., BOSTON.

[*Read March* 10, 1897.]

The city of Ashland, Wis., is in latitude 46° 34′ N., being substantially the same as that of Quebec, Canada, and about one degree farther north than Montreal. It is situated upon the southerly shore and near the head of Chequamegon Bay, an arm of Lake Superior, whose length from southwest to northeast is about twelve miles, and whose width ranges from two and a half miles at the head to six miles in the widest part near its mouth, its total area being about fifty-six square miles. Extending nearly two thirds the way obliquely across the mouth of the bay is an insular sand spit about five miles long and from three hundred to fifteen hundred feet wide, known as Long Island or Chequamegon Point, which forms a natural breakwater for the bay. Between the northwesterly end of the island and the mainland lies the main channel, about two and a half miles wide, while the southeasterly end is about a quarter to half a mile distant from the point of the mainland on the south. The southeasterly channel was naturally shoal, and somewhat variable in both depth and width.

The natural circulation of the water at the head of the bay, including the harbor and anchorage of Ashland, was somewhat impeded by the construction (by the United States Government), from 1890 to 1892, of a breakwater 7,350 feet long, which, beginning about three thousand feet from the Ashland shore, one and three fourths miles northeast from the pumping station, extends northwesterly to within two and a half miles of the opposite shore. That portion of the bay thus partially impounded has an area of twelve square miles, and into it discharge creeks and rivers draining about one hundred and fifty square miles of watershed composed of red clay and alluvium. Farther down the bay enter other streams draining some two hundred and fifty to three hundred square miles more of similar territory. During the spring thaws and freshets and

in times of heavy rainfall these streams are heavily charged with red clay and mud which impart their characteristic color and substance to the waters of nearly the entire bay.

In 1894 the gap at the southeasterly end of Chequamegon Point was closed up by the government for the purpose of extending and strengthening the protection which the island afforded to the land-locked waters of the bay. The closing of this gap is believed by those who have studied the problem to have still further diminished or checked the natural circulation of water in the bay by compelling the inflowing current moving westerly along the northerly shore, and which formerly found its outflow through the said gap, to return upon itself within the bay, and find its present outflow into the main lake along the opposite side of the channel by which it enters.

The city of Ashland was incorporated in 1887. Its territory comprised a part of that previously contained in the town of Ashland and some "Additions" adjacent thereto, leaving unincorporated a portion only of the original town.

By the United States census of 1880 the town of Ashland as then constituted had a population of 951. By the United States census of 1890 the population of the city of Ashland was 9,956, and that of the town outside of the city limits 1,507, making the total population of the territory under consideration 11,463. The present population of this territory is estimated at about 15,000.

The water works were constructed in 1883, and water first introduced early in 1884 by the Ashland Water Company. The works were built under the direction and control of the Holly Manufacturing Company of Lockport, N. Y., and the method of supply is the well-known Holly system of direct and continuous pumping according to the current demands of the service. The original pumping plant comprised two 1,500,000-gallon Gaskill pumping engines. The pumping station is located near the easterly verge of the populated district upon the water front, and the supply was first obtained directly from the bay through a 16-inch wrought-iron intake pipe extending about two thousand feet out from the shore.

In 1889 a new intake of 24-inch cast-iron pipe was constructed. It was laid in a dredged channel, and extends about five thousand feet out into the bay to a contour about twenty-two feet below mean

water. It deflects somewhat to the eastward and away from the harbor in front of the city, so that its outer end extends to within about one mile of the farther end of the breakwater.

In 1888 sewers were first constructed by the city in some of the principal streets, and have since been gradually extended. They are upon the separate system, and discharge directly into the bay at three different points along the water front, all being west or toward the head of the bay from the pumping station.

In 1891 the principal stock holdings in the company changed hands, and the new interests, so created, resulted in a complete change in its management. Large additions to the distribution system were made coincident with extensions of the fire service ordered by the city, and these were followed by more sewers, and by an increase in the pumpage, to provide for which a 4,000,000-gallon Deane pumping engine was installed in 1894.

The consumption of water in 1891, as determined from the imperfect records kept at that time, averaged from 800,000 to 1,000,000 gallons per day. In 1895–6 (March 1 to March 1), it had increased to an average of 1,343,219 gallons, and fell back in 1896–7 (under some increase in the use of meters) to 1,340,032 gallons per day, of which 250,000 gallons and upwards daily are of ground water supplied by the collecting well, to be described farther on.

In 1893 and 1894, Ashland, in common with many other communities in northern Wisconsin and Michigan, experienced an epidemic, variously termed by physicians "winter cholera," "typhoid fever," "typhoid malaria," etc. It appeared in small communities having no aqueduct system of supply, — in cities whose municipal water sources were open to the suspicion of contamination by sewage, in others where some degree of pollution was certain, and in still others where the purity of the water supply was unquestioned. Among physicians and people there was a division of opinion as to the identity of the disease and the chief agencies of its transmission, but in the minds of some of the leading authorities in the State, familiar with the symptoms of the disease and the conditions under which it appeared, it was thought not to be true *typhus*, and that other causes than impure water contributed to its wide distribution. The sudden appearance of the epidemic throughout so wide an extent of country, and its equally sudden abatement, seemed to indicate that in some

cases, at least, public water supplies were charged with a larger share of responsibility therefor than was their due.

At Ashland, however, the menace to the purity of the water supply which was created by the construction of the city sewers in 1888, supplemented by the alarm to which the epidemic gave rise, led the company to devise measures that would not only satisfy the standards of its own advisers, but also remove any just occasion for alarm upon the part of its patrons and the municipal authorities. To this end, new sources of supply were considered. The open lake was at so great a distance, — ten miles in an air line, — as to make the cost of going there prohibitive. The extension of the intake beyond the breakwater would still afford a supply from the bay only, — subject to discoloration during freshet stages of the streams contributing thereto, and to such modified chances of contamination as would ensue from getting somewhat farther away from the sewers of Ashland, but at the same time nearer to the sewers (present or prospective) of the town of Washburn situated about five miles away on the other side of the bay.

Certain springs west of the town of Ashland, about four miles from the pumping station, might have been utilized by abandoning the present station altogether, and readjusting the entire arterial system to a new heart of the works, and while the necessary consent of the city government to the substitution of a somewhat hard spring water for the softer water of the bay might have been forthcoming, the cost thereof was again practically prohibitive.

Ground water is found along the water front of the city of Ashland at a depth of from thirty to fifty feet below the lake surface. The water-bearing stratum at the pumping station is found at a depth of about thirty feet below the surface of the lake. It is about thirty feet in thickness, rests upon red sandstone, and is overlaid by a hard, compact, and impervious pan of red clay mixed with gravel and some bowlders. The thickness of the superimposed hard-pan increases back from the shore by reason of the increased elevation of the ground surface. The static head or pressure of this ground water, along the vicinity of the shore, is about fourteen feet above the level of the lake, and the quantity and quality of the free outflow obtained at lower levels, from some tubular test wells sunk early in 1894, afforded the prospect of obtaining a partial supply at least, whose value would be commensurate with its cost, even if filtration of the bay water

should ultimately be found to be necessary. During the last half of that year, therefore, the company constructed a large circular collecting well, 58 feet 4 inches in diameter, and extending down entirely through the hard-pan to the water-bearing stratum 32.50 feet below the lake level and 39.00 feet below the finished ground line around it. This well now overflows at 4.50 feet above the lake, and contains in store 20,000 gallons for each foot of its depth below the overflow, 37 feet, or a total of about 740,000 gallons.

Ten 6-inch tubular wells were also sunk upon the pumping station premises, all within an area, 280 feet square. These are connected up with the collecting well by pipes laid at about the level of the lake, and draft by siphonage whenever the water in the main well is drawn below that level.

The collecting well flows freely, and yields or overflows at the rate of 252,000 gallons daily at 4.50 feet above the lake level. At the level of the lake, the free flow amounts to about 325,000 gallons daily, while by drafting down to ten feet below the lake (the greatest depth practicable with the pumping machinery in its present position) the normal yield or flow amounts to about 450,000 gallons per day.

The original plan for a supply of ground water contemplated a possible extension of the tubular well system along the water front of the city outside the premises of the company to such distance as should be found needful to procure the requisite quantity. Meanwhile, the experience of the writer, with various systems of mechanical filtration of public water supplies at other places, and a study of the possibilities of the slower process of sand filtration as illustrated by the open filter at Lawrence, Mass., and also in European practice, so well described by Mr. Hazen in his work on "Filtration of Public Water Supplies," which appeared early in 1895, and by the investigations and reports of others, led to the ultimate adoption of slow filtration through sand as the best solution of the problem.

The policy of the Water Company upon this question was submitted by the writer in July, 1895, to a committee of citizens and members of the city government, to whom the matter at issue had been referred for consideration and report. The committee reported favorably thereon to the City Council, with resolutions for carrying its recommendations into effect, and upon the 5th of August the report was adopted and the resolutions were passed by the Council and accepted in behalf of the company, which was thereby committed

to the construction of an earth and masonry covered filter for the filtration of the entire supply of bay water to be furnished by it.*

The pumping station lot fronts one hundred and fifty feet upon the bay, between a public street on the west (Twelfth Avenue east) and private owners on the east. The land area between the engine house and the natural shore line was not only insufficient for the filter but was already occupied by the collecting well and other appurtenances of the station. Across the extension of the lot into the bay, and at a distance of fifty to one hundred and twenty feet from the shore, is a siding of the Chicago & Northwestern Railroad, a right of way for which, sixteen feet wide, had been granted by the Water Company in 1886.

The most practicable location for the filter at or near the pumping station was clearly that contained between the extension of the side lines of the company's property into the bay, for which purpose the gradual slope of the bottom, the nature of its material, and the favorable opportunity afforded for placing the works below the level of the lake to operate by gravity, made the advantages of the site apparent.

The net area of the filtration surface is approximately half an acre, contained in three compartments, numbered 1, 2 and 3, respectively. No. 1 is on the land side of the railroad track and occupies a portion of the margin of the bay, naturally shoal, that had been filled up with slabs and earth before this work was undertaken. It is one hundred and forty feet long by fifty-two feet wide inside, and contains two rows of piers, seven in each row, for the support of the covering arches, the horizontal section of each pier being 4.75 square feet. Compartments 2 and 3 are entirely outside the railroad track, where the mean depth of the water was from four to seven feet. Each of these compartments is one hundred and four feet long by seventy feet wide inside, and contains three rows of piers, having five in

*Extract from report of joint committee above referred to:—

"The first item in importance is the question of pure water. The company proposes to adopt the filter bed system, largely used in European cities, where the source of water supply has been contaminated by the sewage from populations numbering into the millions. The result, as published in Hazen's work on Filtration, would indicate that the system of filtration there used removes both physical impurities and bacteria from the water. . . .

"The committee submits herewith a resolution which embodies the substance of our negotiations with the Water Company representatives, and which, if adopted by the Council and accepted by the Water Company, will constitute a contract, and will settle all differences now existing."

each row, for the support of the covering arches, the horizontal section of each pier being 4.433 square feet.

The entire water area occupied by the filter was first enclosed on its three water sides with a permanent coffer-dam or bulkhead, for the double purpose of excluding the water of the lake during the construction of the works, and for their permanent protection thereafter. Those portions of the dam along the two sides of the property were placed just outside the property lines with the consent of the adjacent owners, thus leaving the full width between the lot lines for the filter itself. The dam consists of two rows of round piling driven from seven to eight feet apart in the rows, the piles in the two rows being opposite each other, and the rows ten feet apart on centres along the two sides of the work, and twelve feet apart in that portion against the outer end.

The piles are driven from six to eight feet into the hard-pan bottom, and cut off at a uniform height of about five and a half feet above mean water. At the water level, and also at the top of each row, continuous eight-inch by eight-inch stringers or rangers are notched into the faces of the piles that are toward each other, and against the rangers, lines of three-inch sheeting are driven. The outer row of piling is braced at each pile by shores driven between the rows, and drawn over and bolted to each pile through the stringer placed at the water line. The two rows are securely tied or trussed to each other at each pile by a panel of vertical cross braces and tie-bolt placed above the water level, as indicated in the accompanying drawing, and fender piles driven at the outside corners. The space between the two lines of sheeting was then filled with material that had been excavated from the collecting well the year before, and the water in the enclosed area pumped out.

The grades of the principal features of the works, referred to mean water of the bay, are as follows: —

The bottom of main filter walls, and of partition between compartments 2 and 3, are on hard-pan, at 7.75 feet below mean water.

The piers supporting the covering arches rest on concrete foundations, four feet square and one foot thick, — bottom of foundations being 8.75 feet below mean water.

The finished floor of filter compartments along walls, partition, and pier lines is 7.50 feet below mean water. Along the channels for the collecting drains the floor is made lower, — according to the varying

diameters of the pipes, to bring the tops of the pipes to the uniform height of 7.50 feet below mean water.

The walls and partitions of the effluent chamber, pump well, and sump well are on concrete foundations nine inches thick, the bottom of which is at 10.50 feet below mean water, while their floors are at an average grade 9.50 feet below.

The outside walls are three feet thick at the bottom and two feet at the springing line of the covering arches. They are of composite construction, consisting of a brick facing and a backing of cement concrete. The facing is twelve inches (three brick courses) thick in the lower part, and eight inches (two courses) in the upper. At intervals of twelve feet, against the back side of the facing, buttresses of the same material, two courses thick, were built up and bonded therewith, — the depth and batter of the buttresses being the same as of the concrete backing filled into the spaces between them to complete the wall.

The brick work is laid in Portland cement mortar. All concrete in the work is also of Portland cement, mixed with bank sand and beach gravel or pebbles, in the proportions of one, two and a half, and five parts, respectively.

All piers and partition walls are of brick, laid in Portland cement mortar, all mortar used being of two parts of cement to three of sand.

The vertical joints between the faces of all the walls and piers and the filter bed are broken by two horizontal ledges or offsets of two inches each in width at 1.75 and 3.25 feet respectively above the floor level of the filter compartments, both ledges being within the limits of the sand stratum.

The piers are spaced 15.75 feet apart in the clear, each way, from each other and from the adjacent walls in each of the three filter compartments, which, with the pump well, are covered by groined elliptic arches of 15.75 feet span and 3.50 feet rise. The arch rings are about five inches thick, consisting of two courses of bricks laid flatwise in Portland cement mortar. The spandrels of the arches and the spaces over the piers and adjacent walls are filled and covered with a backing of Portland cement concrete up to a general level of four feet above the spring of the arches, but sloping down to a height of two feet only above the springing line at the rear of the outside walls.

The arches covering compartments 2 and 3 were the first to be turned, centres for which were provided for their full area at the outset. When these arches and their concrete backing were completed the centres were removed, and enough material taken from them for centering compartment 1 and the pump well.

The bricks in the arches are laid in uniform horizontal courses, and cut or mitred to fit the angles of their intersections, except in a few courses next the springing lines, and also at and near the crowns where the corresponding courses of the intersecting arches are neatly bonded with or into each other without cutting.

At the alternate intersections of the arches manholes to the number of twelve in each compartment afford access and admit light to the vaulted spaces below, during the process of cleaning and replenishing the filter beds.

Upon the concrete backing which overlays the covering arches, and between the main walls and the coffer-dam which enclose the work, the earth is backfilled and neatly graded and seeded. The total thickness of the earth covering is two feet over the main part of the filter, or 6.50 feet above mean water, sloping down to 5.50 feet above mean water at the outer face of the coffer-dam.

The piers in compartment 1 carry a permanent load computed at 23,985 pounds per square foot of horizontal section, and those in Nos. 2 and 3, 25,460 pounds per square foot.* This load was temporarily increased, while the work was still new, to about fourteen and a half tons per square foot, in the case of two piers, by inadvertence on the part of some of the laborers, in piling a quantity of Portland cement in barrels upon the earth filling over them. No injury resulted therefrom, nor was any weakness disclosed thereby.

The effluent chamber and sump well are covered by a brick house containing the gate stands and hand wheels for controlling the flow from the various compartments, and an 8-inch centrifugal pump with Westinghouse engine for pumping out any desired compartment through the sump well.

---

*The weights of materials allowed in computing the loads on piers, including water of absorption, are as follows: brick work, 130 pounds per cubic foot; concrete, 160 pounds per cubic foot; earth covering, 115 pounds per cubic foot. The snowfall at Ashland is large, and an allowance for its accumulation upon the earth covering of the filter, to an amount equivalent to four inches in depth of water, would add to the load on the piers in compartment 1, 1,409 pounds per square foot, and in compartments 2 and 3, 1,497 pounds per square foot.

The bottoms of the filter compartments, effluent chamber, and pump well are floored with Portland cement concrete three inches thick. Along the lines of the collecting drains the depth of the concrete flooring is increased, and channels — half-hexagons in section — are formed therein to receive the drains. These drains are of vitrified sewer pipes in two-foot lengths, ranging in diameter from four inches at the head of each lateral to ten inches at the main outlet pipe, by which each compartment is connected with the effluent chamber.

The depths of the channels in which the collecting pipes are laid are half the external diameter of the bells of the pipes. A line of laterals extends along the centre of each colonnade in the direction of the greatest dimension of each compartment. For about one third of their length at their upper ends the laterals are of 4-inch pipe, enlarged to 5 inches for the middle third, and to 6 inches for the lower third, at which size they connect with the transverse collecting drains of 8-inch and 9-inch pipes leading to the 10-inch cast iron effluent pipe.

The raw water is supplied to each compartment through a 10-inch cast iron pipe branching from a 16-inch main which leads from the intake well into which the water is received from the bay.

The sand beds proper have a maximum thickness of about four feet. They are supported upon three layers of selected gravel stones of graduated sizes of grain for subdrainage. Of these the first or lower stratum of pebbles has a thickness of nine inches at and along the lines of the drains, and six inches midway between them, and next the walls. The second and third layers from the bottom are about two inches and an inch and a half respectively in thickness throughout, making the full depth of the beds five feet at the drains and four feet nine inches midway between them.

The gravel comprising the three strata which support the sand beds (together with that for concrete) was brought from the beach on the north shore of Lake Superior, near Two Harbors, Minn., a distance of about eighty miles, by water transportation. It cost by contract per cubic yard on the dock at Ashland, $1.80 in the fall of 1895, and $1.50 in August, 1896. This material ranged in size of grains from about 0.50 m. m. in diameter to stones two inches across in their greatest dimension. It was passed over two screens, whereby it was separated into the three desired grades. Of these the coarser — used for the bottom layer — is such as did not pass

through a screen having two meshes per lineal inch. That used for the second layer consists of such as passed through the screen of two meshes but not through one of four meshes per inch, while the finer grade upon which the sand rests is of the portion that passed through the screen of four meshes per inch.

The sand used for the filter beds in compartments 2 and 3 was drafted through the suction pipe of an 8-inch centrifugal pump from the bottom of the bay, just inside Chequamegon Point, and was delivered on the dock at Ashland in the fall of 1895 at sixty-five cents per cubic yard by contract.* That used in making the filter bed in No. 1, and in replenishing Nos. 2 and 3, was obtained from the beach at Big Bay, Madeline Island, about twenty-four miles from Ashland by water, and was delivered through manholes into the compartments (but not placed) in August, 1896, at ninety cents per cubic yard by contract.

These sands are similar in appearance and character. They are of fine but exceedingly uniform size of grain, that of 1895 from Chequamegon Bay having an "effective size" of 0.27 m. m., with a "uniformity coefficient" of 1.9, while that of 1896 from Madeline Island has an "effective size" of .40 m. m., and a "uniformity coefficient" of 1.6, according to the standard of measurement adopted by the Massachusetts State Board of Health in the Lawrence Filtration Experiments.† The sand from Chequamegon Bay contained a few

* Mr. A. H. Salisbury, Superintendent of the Lawrence Water Works, informs me (March, 1897) that it costs sixty-eight cents per cubic yard to *wash* the sand removed from the Lawrence filter, in the process of cleaning, not including the cost of replacing it on the filter bed. — W. W.

† Analyses, by the writer, of the two varieties of sand actually used in the construction and replenishing of the Ashland Filter beds, show the following results, to which are subjoined, for comparison, like analyses of single samples of two grades of bank sand (new) used in the open filter of the Lawrence Water Works, and of a sample of old sand that had been washed preparatory to replacing it on the filter bed: —

Samples Analyzed.	Effective Size.	Uniformity Coefficient.
Ashland sand, Chequamegon Bay, October, 1895	.27 m. m.	1.9
" " Madeline Island, August, 1896	.40 m. m.	1.6
Lawrence, new sand, No. 50, March, 1897	.21 m. m.	4.4
" " " " 70, " 1897	.30 m. m.	5.1
" washed sand, " 1897	.40 m. m.	2.5

Analyses of four samples of sands, available for use in the Ashland Filter, made by Mr. Allen Hazen, prior to the construction of the work gave the following results: —

Samples analyzed.	Effective Size.	Uniformity Coefficient.
Fine Bank sand	.26 m. m.	1.6
Coarse Bank sand	.33 m. m.	1.6
Lake sand, locality not reported	.30 m. m.	1.5
Beach sand, Bayfield shore	.38 m. m.	1.6

gravel stones, which were separated by screening. It was procured during the latter part of October, 1895, and was discharged from scows by pumping into bins on the dock. When the two compartments first completed — Nos. 2 and 3 — were ready for their sand beds in December, 1895, and January, 1896, the sand was frozen solid. It therefore had to be thawed and dried by artificial heat before it could be screened or used. For this purpose a multi-tubular furnace was improvised from six 12-foot lengths of 16-inch water pipe arranged in a battery of three horizontal flues, each 24 feet long, and placed 4.50 feet apart on centres, and parallel to each other. A 12-foot length of 8-inch water pipe set up and connected vertically at the spigot end of each flue afforded the draft necessary to maintain combustion in the flues, fuel for which was cheaply and conveniently furnished in the form of slabs. The sand to be heated was piled upon the horizontal pipes and around the vertical ones to the depth of three or four feet in a large bin enclosing all but the bell ends, through which the fires were fed. The sand and gravel used for mortar and concrete during freezing weather were also heated in the same manner.

The impervious character of the hard-pan, on which the filter is built, and somewhat of the thoroughness with which the coffer-dam and the masonry were constructed are indicated by the fact that the entire amount of seepage into the whole area of the works (all of which drained into the sump well, at a depth of about ten feet below the level of the bay) amounted in ninety-six hours to about one thousand eight hundred and sixty gallons, being at the rate of about one gallon in three minutes.

The entire works, with the exception of the filter bed in compartment No. 1, were substantially completed, and the gate in the only connection between the raw water intake and the pumps was closed Feb. 5, 1896,* just six months after the work was determined upon, within which time all plans and specifications had also to be prepared therefor. Thenceforth the entire supply has been filtered with the exception of the ground water overflowing from the collecting well, as above described. The above date is believed to mark the completion and beginning of operation of the first masonry covered filter of its type in America.

---

* At the suggestion of the writer, this gate was sealed Feb. 10, 1896, in the presence of the City Physician and the Superintendent, who reported March 2, 1897, that the seal "has never been broken or disturbed since."

The works were designed by the writer, and constructed by day labor under the personal oversight and direction of Mr. Sam Wheeler, the superintendent of the company.

The discharge of the overflow of ground water into the effluent chamber was continued until July 9, 1896, when (in order to permit the taking of samples of the filtered water, unaffected by the ground water, and without temporarily increasing the rate of filtration by its exclusion from the supply during such taking) it was permanently turned into the filtered water pump well.

Compartment No. 1 was provided with its filter bed in August, 1896, Nos. 2 and 3 only having been in service up to that time. The bed in No. 1 was completed and placed in operation Sept. 1, 1896. From Sept. 2 to 8, sixteen inches of sand were added to the bed in No. 2, of which about 11.50 inches represented the sum of the settlement that had taken place in the original bed, and the amount removed in the eleven cleanings thereof since Feb. 5, while the balance, 4.50 inches, was an addition required to bring the bed up to its full standard depth. No. 2 was again placed in operation Sept. 8, after which, — Sept. 9 to 13, — No. 3 (which likewise had been cleaned eleven times since February) was replenished and added to in the same manner, and placed in operation again on the last named date. Since then, all of the compartments having been in constant service, except when being cleaned, the cleanings have been much less frequent than before, as will be seen by reference to the accompanying tabulations of the operation of the filter, No. 1 having been cleaned three times, and Nos. 2 and 3 only two times each, from Sept. 13, 1896, to March 1, 1897. The greater frequency of cleaning previously required was doubtless chiefly occasioned by the smaller area of filtration then in use, and by the greater turbidity of the water during the spring freshets, but it is believed to have been materially affected also by the fact that several dredges were at work at the ore docks near the station during the summer, and the excavated material conveyed in scows over the outer end of the intake, and dumped into the bay near the breakwater.

The cost of the completed work as made up and classified from the books of the Treasurer and the notes of the Superintendent is summarized as follows: —

COVERED SAND FILTER AT ASHLAND, WIS.

Summary of Cost of Construction.

Coffer-Dam:		
470 lineal feet, approximately, exclusive of earth filling		$1,720 05
Excavation:		
6,943 cubic yards, used in coffer-dam, over arches, behind side walls, under railroad, and wasted (of which 700 cubic yards were handled twice),		3,233 15
Handling Water		493 00
Brick Masonry:		
340,400 bricks laid in side and partition walls	$6,236 89	
45,000 bricks in piers	826 75	
349,550 bricks in covering arches (and some in backing)	6,755 23	
37 manholes, including iron frames, covers, and setting in brick work	724 31	
		14,543 18
Centres for Groined Covering Arches:		
Materials, erection and removal		1,156 59
House over Effluent Chamber and Sump Well		626 79
Concrete:		
1,000 cubic yards, in place		5,976 57
Collecting Pipes:		
Vitrified pipe, laid	$116 34	
Cast iron pipe, specials, and valves, laid	639 14	
		755 48
Supplying Pipes:		
Cast iron pipe, specials, and valves, laid		725 46
Pipe Connections:		
Between pump well and sump well, effluent chamber, collecting well, centrifugal pump and pumping engines, cast-iron pipe, specials, and valves, laid		728 70
Filter Beds:		
880 cubic yards gravel in three lower strata	$1,949 30	
3,335 cubic yards sand in upper stratum	4,201 40	
		6,150 70
Sundries, not otherwise classified		2,267 95
Engineering and Superintendence		1,800 00
Total cost		$40,177 62

With the railroad track out of the way and the entire filtration area of one half acre constructed in one compartment, the reduction in cost consequent thereon would have been about $2,866.73.

The cost of the filter was much increased also by the inclemencies of the weather during the months of November and December, 1895, and January, 1896, in which all the masonry of compartment No. 1 and of the effluent chamber, sump well, and pump well, and the sand bed in compartments 2 and 3 were constructed. A careful consideration and estimate of the additional cost due to working in cold weather, short days and night work, indicate that the extra expense occasioned thereby was not less than $2,500.00.

The sum of these ($5,366.73) deducted from the actual cost ($40,177.62) leaves as the estimated normal cost at Ashland of a filter of this type of one half acre in one compartment (including effluent chamber, pump well, sump well, piping, and housing), $34,810.89.

In localities where good building stone and suitable gravel and sand are near at hand, this cost should be reduced from ten to fifteen per cent.

The course of procedure in scraping or cleaning one of the filter beds is as follows: —

The need of cleaning is indicated by the head under which filtration takes place, which is shown approximately by the difference in level at which the water stands on the bed and in the effluent chamber and pump well, the gate in the effluent pipe being wide open. Under the present practice, cleaning is deferred until the gradual increase in head incident to the arrest of foreign matter on and in the upper part of the bed causes the water in the effluent chamber to fall from six inches to one foot below the top of said bed, indicating that the maximum head for the compartment to be cleaned is from three to three and one half feet.

On the day before cleaning, the raw water supplied to this compartment is stopped and the water stored therein continues to drain off through the sand into the effluent chamber until it stands about a foot below the top of the bed — this condition being usually reached by the following morning, — when it is ready for cleaning.

The tool commonly used for scraping is a two-edged wooden scraper or hoe, the blade of which, made from a ⅞-inch board, is about fifteen inches long by six inches wide, with a handle joined perpendicularly thereto at its centre. The two cutting edges are bevelled at an angle of about forty-five degrees.

The sand removed is usually muddy and somewhat slimy on the top when wet, and forms a slight crust when allowed to dry. The mud and discoloration, which determine the depth of removal, extend from one-half to three-fourths of an inch down into the sand, and impart an adhesive quality to the sand, by virtue of which in cleaning, the scraper seems to follow a line of cleavage between the foul and clean portions of the bed.

After a bed has been cleaned the connection between the ground water well and the filtered water well is partially opened, and the water level in the effluent chamber gradually raised thereby until the newly cleaned bed is fully submerged to the depth of about a foot by the filtered or clear water, after which the raw water inlet is opened, the ground water again excluded, and the cleaned filter is thus again installed in service.

The time required for cleaning one of the beds of one-sixth of an acre is half a day, and the total cost thereof about $8.50, made up as follows: —

3 men scraping	½ d. at	$1.50 each,	$2 25
2 men wheeling in filter	"	1 50 "	1 50
1 man tending bucket at bottom	"	1 50 "	75
2 men to land and dump bucket at top	"	1 50 "	1 50
1 man wheeling away on top	"	1 50 "	75
1 single team to hoist bucket	"	2 50 "	1 25
Tools and sundries			50
			$8 50

This is at the rate of about $50 per acre per cleaning, not including replenishing.

The entire cost of cleaning and maintenance, including that of restoring the sand removed, for one year, to Feb. 28, 1897, is estimated as follows: —

Number of compartment cleanings, 29.	
Labor for each scraping, using such men employed about the works as are available, and hiring others at an extra expense of $4.50, but charging all labor employed as above	$8 50
Cost for 29 cleanings	246 50
Average reduction in depth of sand beds, taking all three compartments into consideration, is about nine inches, to replenish which requires 610 cubic yards, at $1.00 placed	610 00
Making cost of cleaning and replenishing	$856 50
Add for contingencies and superintendence, 5%	42 87
Total cost	$899 37

Average per cleaning, including replenishing, per compartment,	$31 01
Average per cleaning, including replenishing, per acre . .	186 06
Million gallons filtered, March 1, 1896, to Feb. 28, 1897 . .	397.86
Cost per million gallons filtered, not including interest on plant,	$2 26

The average rate of filtration per acre per day (rated on one-half acre in use) was 2,180,064 gallons.

The interest charge per million gallons filtered, computed on the actual cost of the plant, at the different rates indicated below, and added to the above cost of operation, gives the following results: —

RATE OF FILTRATION 2,180,064 GALLONS PER ACRE PER DAY.

Rate of Interest.	Interest Charge per Million Gallons.	Cost of Operation per Million Gallons.	Total Cost of Filtration per Million Gallons.
6 per cent . . .	$6 06	$2 26	$8 32
5 " " . . .	5 05	2 26	7 31
4 " " . . .	4 04	2 26	6 30

Increasing the rate of filtration within moderate limits, say to not exceeding 3,000,000 gallons per acre per day, would not materially affect the operating cost per million gallons filtered, since the number or frequency of cleanings would be approximately proportional to the rate of filtration. The interest charge per million gallons filtered, however, is inversely proportional to the rate of filtration or the amount filtered. Thus if the rate of filtration were 3,000,000 gallons per acre per day, the interest charge and total cost of filtration resulting therefrom at the several rates of interest indicated would be as follows: —

RATE OF FILTRATION 3,000,000 GALLONS PER ACRE PER DAY.

Rate of Interest.	Interest Charge per Million Gallons.	Cost of Operation per Million Gallons.	Total Cost of Filtration per Million Gallons.
6 per cent . . .	$4 40	$2 26	$6 66
5 " " . . .	3 67	2 26	5 93
4 " " . . .	2 93	2 26	5 19

The cost of operation will vary in different years according to the variable conditions of the problem, such as duration and degree of muddiness of water in the bay, cost of sand, improvement in method, etc.; and in making deductions from the experience at Ashland, for the proper study of the problem of filtration at other places, all such conditions must be carefully compared and considered.

First among the conditions which experiment and experience in slow sand filtration have shown to be prerequisite to a high degree of efficiency, as indicated by comparative bacterial analyses of the raw and filtered water, is the lapse of time necessary for the establishment of bacterial life or soil organisms throughout the filter bed, whereby the individual sand grains appear to become invested with or covered by a gelatinous coating of "zoögloea" upon the chemical or organic action of which the removal or destruction of pathogenic germs by the filter is believed to largely depend. The process is therefore *vital* as well as mechanical, and the time required to develop this condition Mr. Hazen has aptly termed "the period of biological construction."

The development or establishment of such a biological organization *where the sand composing the filter bed has not been sterilized* or its natural bacterial condition has not been materially changed has been found to be a process requiring some months, and indeed some of the Lawrence experiments tend to show a constantly increasing bacterial efficiency during the first two or three years' operation.

It appears further to have been well established by experiment that a filter bed of sand which has been *sterilized by heating* yields for a time an effluent containing relatively more bacteria than one of unsterilized sand, sometimes more than were contained in the raw water. Such results have been attributed to the inferior or impaired efficiency of the sterilized sand in destroying or removing the bacteria of the raw water, but the Lawrence experiments appear to indicate in some cases at least "that the high numbers, often many times as high as in the raw water, do not represent bacteria which pass in the ordinary course of filtration, but instead, enormous growths of bacteria throughout the sand supported by the cooked organic matter in it." *

It should be here stated, however, that the investigations thus far made at Ashland show that the bacteria in the filtered water have borne some relation in numbers — although not clearly so in kind, so far as varieties have been differentiated — to those found in the raw water at the same time.

To what extent, if any, a sand drafted from the bed, or taken from a beach of Lake Superior, may be lacking in those normal *soil*

* Hazen, Filtration of Public Water Supplies, p. 81, 1st edition.

bacteria, upon the existence of which throughout the filter bed its efficiency in the removal and destruction of water bacteria is believed to largely depend, or what additional length of time may be required to establish and complete in such sand, or in sand sterilized by heat, the process of biological construction referred to is a question to which, so far as I have been able to learn, neither experience nor experiment has yet supplied the answer. That such period must be greater than in the case of sand from land sources, in which the normal bacterial conditions have not been changed by sterilization or otherwise, can hardly be doubted, and the possible significance of such considerations should not be overlooked in considering the bacterial efficiency of the Ashland filter during the first year or more of its operation in view of the fact that the sand in two of its compartments was in all probability completely sterilized by the heating process to which it was subjected during the winter season in which it was constructed, and that all of the sand was obtained from sources and by processes which subjected it to a very thorough washing with clear lake water, whereby such bacteria as remained in it were presumably of water rather than soil varieties.

Other conditions which contribute to a low efficiency of filtration during the first year's operation of this filter, all of a temporary character are —

(*a*) The high average rate of filtration necessitated during the use of two compartments only, during the first seven months of that period, and one only when the other was being cleaned.

(*b*) Fluctuations in the rate of filtration at the time samples were taken during the first part of that period, by reason of the exclusion of ground water during the half hour of taking.

(*c*) The time intervening between the taking of the samples at Ashland and the biological examination of the same at Madison, — usually a full day.

(*d*) The lack of automatic regulation of the rate of filtration upon each of the several filter beds, for which provision is now being made.

Notwithstanding these considerations and the incomplete stage to which the filter had been brought, the city authorities, at the suggestion of the writer, instructed the Health Commissioner, Dr. E. D. Perkins, to have biological analyses of the raw and filtered water made "every thirty days or oftener," beginning with the first

Operation of Sand Filter at Ashland, Wis., and Bacterial Analyses of Results by Prof. H. S. Russell, of Madison, Wis.

TABLE A, covering first period from Feb. 8, 1896, to July 3, 1896.

CONDITIONS. — Compartments Nos 2 and 3 only, in use. Filtration Area, 1/3 Acre. Compartment No. 1 (having no filter bed), in open connection with Effluent Chamber and Pump Well. Overflow from Collecting Well into Effluent Chamber, amounting to 252,000 Gallons daily, is continuous, except for a short time (about thirty minutes) before samples are taken, during which interval said overflow is excluded, thereby increasing the daily rate of filtration during that time by 252,000 ÷ 1/3 = 756,000 Gallons per Acre.

Samples Taken.	Samples received at Madison.	Temperature Fahr. on arrival.	Bacteria Found, Number per cc.			Analyst's Remarks.	Approximate Rate of Filtration per Acre in Gallons per Day.			Compartments of Filter Cleaned.	
			Unfiltered.	Filtered.	Apparent reduction per cc. by Filtration, per cent.		When samples were taken.	Maximum since previous sample was taken.	Minimum since previous sample was taken.	Date.	Compartment.
1896.											
Feb. 19, 5.00 P. M.....	Feb. 20 ...	41.	1,475	1,258	14.7		5,517,600	5,517,600	2,589,600		
Feb. 26, 5.00 P. M.....	Feb. 27 ...	41.	960	870	9.4	Gas-producing bacteria present in unfiltered sample, absent in filtered.	4,620,000	4,846,800	3,012,000		
March 27, 5.00 P. M.....	March 28..	41.	4,500	1,000	77.7		5,029,200	5,110,800	2,642 400		
April 10, 5.00 P. M.....	April 11...	44.	5,310	425	92.		4,382,400	4,382,400	2,695,200		
April 24, 5.00 P. M.....	April 25...	44.	19,000	10,300	45.8		4,290,000	4,290,000	2,259,600		
										April 27	No. 3.
										April 28	No. 2.
May 1, 5.00 P. M.....	May 2....	52.	68,800	48,000	30.2		3,788,400	6,736,800	2,088,000		
May 8, 4.30 P. M.....	May 9....	52.	2,230	1,760	21.1		4,540,800	4,540,800	2,048,400		
May 15, 4.30 P. M.....	May 16....	40.	1,000	320	68.		4,646,400	8,067,600	2,312,400		
										May 18	No. 3.
										May 19	No. 2.
May 22, 4.30 P. M.....	May 23....	44.5	185	37	80.		4,950,000	7,106,400	2,233,200		
										May 29	No. 3.
										June 1	No. 2.
										June 10	No. 2.
June 12, 4.30 P. M.....	.....	43.	4,185	275	93.4	Raw water contains gas-producing bacteria; filtered product, none.	4,237,200	7,687,200	1,956,000		
										June 13	No. 3.
June 19, 4.30 P. M.....	June 20 ...	48.	700	130	81.4	Liquefying forms present in unfiltered sample, absent in filtered; fæcal bacteria absent in both.	5,121,600	7,423,200	2,470,800		
										June 22	No. 2.
										June 26	No. 3.

June 29, 4.30 P. M.....	June 30...	41.	1,115	615	44.9	Species common in unfiltered sample are almost wholly absent in the filtered product.	5,134,800	8,822,400	2,457,600	June 30	No. 2.
July 3, 4.30 P. M.....	July 4....	44.5	2,300	480	79.1	All liquefying and gaseous organisms removed.	4,725,600	8,901,600	2,589,600		

TABLE B, covering second period from July 4, 1896, to July 31, 1896.

CONDITIONS. — Same as in Table A, except that the discharge from the Collecting Well, being diverted from the Effluent Chamber to the Pump Well, flows continuously, thus maintaining the same rate of Filtration at time samples are taken, which obtains before and after.

SAMPLES TAKEN.	Samples received at Madison.	Temperature Fahr. on arrival.	BACTERIA FOUND, NUMBER PER CC.			ANALYST'S REMARKS.	APPROXIMATE RATE OF FILTRATION PER ACRE IN GALLONS PER DAY.			COMPARTMENTS OF FILTER CLEANED.	
			Unfiltered.	Filtered.	Apparent reduction per cc. by Filtration, per cent.		When samples were taken.	Maximum since previous sample was taken.	Minimum since previous sample was taken.	Date.	Compartment.
1896.										July 6 July 10 July 16	No. 3. No. 2. No. 3.
July 17, 4.30 P. M.....	July 18....	41.	1,720	920	46.5	Gaseous and liquefying organisms in both filtered and unfiltered samples.	3,434,400	8,637,600	2,074,800		
July 24, 4.30 P. M.....	July 25....	46.	1,150	150	86.9	Gaseous and liquefying organisms present in unfiltered samples, practically absent in filtered product.	3,698,400	7,317,600	2,167,200	July 21	No. 2.*
July 31, 4.00 P. M.....	Aug. 1...	45.	1,580	408	74.2	Gas producing bacteria present before filtration, but absent in samples taken after.	4,200,000	7,608,000	2,391,600	July 28	No. 3.†

* Compartment No. 3 furnished all the filtered supply from 8.00 A. M. to 1.00 P. M.
† Compartment No. 2 furnished all the filtered supply from 7.00 A. M. to 1.30 P. M.

TABLE C, covering third period from Aug. 1, 1896, to Aug. 31, 1896.

CONDITIONS. — Same as in Table B, except Compartment No. 1, meanwhile receiving its filter bed, is shut off from the Effluent Chamber and so cease to act as a compensating reservoir.

SAMPLES TAKEN.	Samples received at Madison.	Temperature Fahr. on arrival.	BACTERIA FOUND, NUMBER PER CC.			ANALYST'S REMARKS.	APPROXIMATE RATE OF FILTRATION PER ACRE IN GALLONS PER DAY.			COMPARTMENTS OF FILTER CLEANED.	
			Unfiltered.	Filtered.	Apparent reduction per cc. by Filtration, per cent.		When samples were taken.	Maximum since previous sample was taken.	Minimum since previous sample was taken.	Date.	Compartment.
1896.										Aug. 4	No. 2.*
Aug. 6, 11.00 A. M.	Examined at Ashland immediately.	44.	1,625	1,460	10.1	Taken by Prof. Russell, personally. Liquefying bacteria almost entirely removed by filtration.	3,711,600	8,056,800	2,352,000		
Aug. 6, 11.00 A. M.	Examined after twenty hours.	44.	1,820	1,740	4.4	Taken by Prof. Russell, personally. Liquefying bacteria almost entirely removed by filtration.	3,711,600	8,056,800	2,352,000		
Aug. 7, 9.30 A. M.	Examined at Ashland immediately.	.....	2,200 170 Liquefying.	2,700 25 Liquefying.	—22.7 85.3	Taken by Prof. Russell, personally. Filtered sample had more bacteria than unfiltered, but much less liquefying organisms.	3,975,600	4,134,000	3,078,000		
Aug. 17, 3.00 P.M.	Aug. 19...	43.5	1,260	30	97.6	Gaseous organisms present in unfiltered, absent in filtered sample.	3,474,000	6,948,000	2,193,600	Aug. 12	No. 3.†
										Aug. 20	No. 2.‡
										Aug. 28	No. 3.§

* Compartment No. 3 furnished all the filtered supply from 6.40 A. M. to 1.15 P. M.
† Compartment No. 2 furnished all the filtered supply from 7.45 A. M. to 1.15 P. M.
‡ Compartment No. 3 furnished all the filtered supply from 8 40 A. M. to 3.15 P. M.
§ Compartment No. 2, with the Collecting Well, furnished all the supply between 12.30 and 3.45 P. M., and without the Collecting Well furnished the supply from 11.00 A. M. to 12.30 P. M., and from 3.45 to 5.30 P. M.

TABLE D, covering fourth period, from Sept. 1, 1896, to Feb. 19, 1897.

⅛ Compartment No. 2, with the Collecting Well, furnished all the supply between 12.30 and 3.45 P. M., and without the Collecting Well supply from 11.00 A. M. to 12.30 P. M., and from 3.45 to 5.30 P. M.

TABLE D, covering fourth period, from Sept. 1, 1896, to Feb. 19, 1897.

CONDITIONS. — Compartments numbered 1, 2 and 3 in use. Filtration Area, ½ Acre. Overflow from Collecting Well, discharging continuously (as in Tables B and C) into the Pump Well at the rate of 252,000 gallons each 24 hours.

SAMPLES TAKEN.	Samples received at Madison.	Temperature Fahr. on arrival.	BACTERIA FOUND, NUMBER PER CC.			ANALYST'S REMARKS.	APPROXIMATE RATE OF FILTRATION PER ACRE IN GALLONS PER DAY.			COMPARTMENTS OF FILTER CLEANED.	
			Unfiltered.	Filtered.	Apparent reduction per cc. by Filtration, per cent.		When samples were taken.	Maximum since previous sample was taken.	Minimum since previous sample was taken.	Date.	Compartment.
										Sept. 1*	
										Sept. 2	No. 2†
										Sept. 9	No. 3‡
Sept. 25, 5.00 P. M.....	Sept. 26...	41.	450	100	77.7	Vigorous growth of gas organisms in unfiltered sample; none in filtered.	2,518,400	8,400,000	1,374,400		
Oct. 5, 4.30 P. M.....	Oct. 6....	41.	1,085	30	97.2	Liquefying bacteria in unfiltered, none in filtered sample. Unfiltered had bad type of sewage bacteria; filtered, none.	2,615,200	2,668,000	1,242,400		
Oct. 12, 4.30 P. M.....	Oct. 13....	42.	200	40	80.	Small amount of gas-producing germs in unfiltered sample; none in filtered.	2,228,000	3,474,000	1,436,000	Oct. 8	No. 1.
Oct. 23, 4.30 P. M.....	Oct. 24....	37.	850	65	92.3	Copious amount of gas-producing germs in unfiltered sample; none in filtered.	2,580,000	3,196,000	1,436,000		
Oct. 30, 3.00 P. M.....	.....	38.	2,700	30	98.5	Abundant gaseous fermentation in unfiltered sample; none in filtered.	2,404,000	3,606,000	1,524,000	Oct. 27	No. 2.
Nov. 6, 3.00 P. M	.....	37.	2,300	75	96.7	Liquefying and gaseous bacteria quite prevalent in unfiltered sample; none in filtered.	2,052,000	2,316,000	1,260,000		
										Nov. 12	No. 3.

* Compartment No. 1 placed in operation.
† Replenished sand bed in No. 2, increasing thickness of same 4½ inches above original depth and again placed in operation, Sept. 8, 1896.
‡ Replenished sand bed in No. 3, increasing thickness of same 4½ inches above original depth and again placed in operation, Sept. 13, 1896.

TABLE D— *Continued.*

Samples Taken.	Samples received at Madison.	Temperature Fahr. on arrival.	Bacteria Found, Number per cc.			Analyst's Remarks.	Approximate Rate of Filtration per Acre in Gallons per Day.			Compartments of Filter Cleaned.	
			Unfiltered.	Filtered.	Apparent reduction per cc. by Filtration, per cent.		When samples were taken.	Maximum since previous sample was taken.	Minimum since previous sample was taken.	Date.	Compartment.
Nov. 13, 4.00 P. M.	.....	37.	675	88	87.	Unfiltered sample contained organisms of fæcal type; filtered, none.	2,110,000	3,132,000	1,436,000		
Nov. 27, 3.30 P. M.	.....	36.	700	175	75.	Liquefying and gaseous bacteria both present, although to a limited extent.	2,228,000	2,756,000	1,524,000		
Dec. 11, 4.00 P. M.	.....	38.	4,800	1,825	62.	Liquefying and gaseous bacteria present in both filtered and unfiltered samples, although much less in filtered than in unfiltered.	2,492,000	4,002,000	1,700,000	Nov. 28	No. 1.
Dec. 20, 4.30 P. M.	Dec. 21...	37.	2,890	1,860	35.6	Liquefying and gaseous germs present in both filtered and unfiltered samples.	2,048,000	3,474,000	1,684,000	Dec. 12	No. 2.
Dec. 25, 5.00 P. M.	Dec. 26...	39.	7,600	2,300	69.7	Gaseous bacteria present in large numbers in unfiltered sample, but absent in filtered.	2,020,000	2,748,000	1,264,000		
Dec. 29, 10.00 A. M.	.....	41.	.....	2,875	—35.6	Sample from Compartment No. 1, 31 days since cleaning. Bacteria increased in numbers over unfiltered, but no liquefying or gaseous germs found.	2,192,000	3,324,000	1,684,000	Dec. 26	No. 3.
Dec. 29, 2.25 P. M.	.....	41.	.....	2,900	—36.8	Sample from Compartment No. 2, 17 days since cleaning. Bacteria increased in numbers over unfiltered, but all liquefying and gaseous germs removed.	2,300,000	3,324,000	1,684,000		

Dec. 29, 5.00 P. M.		41.		2,500	—17.9	Sample from Compartment No. 3, 3 days since cleaning. Bacteria increased in number over unfiltered but no liquefying and few gaseous germs found.	2,300,000	3,324,000	1,684,000		
Dec. 29, 2.30 P. M.		41.	2,120			Unfiltered sample, with which the three preceding samples are compared, contained copious quantities of both liquefying and gaseous germs.	2,300,000	3,324,000	1,684,000		
1897.											
Jan. 8, 3.30 P. M.	Jan. 9.		4,100	770	81.2	Liquefying and gaseous germs in abundance in unfiltered sample, but no trace in filtered.	2,512,000	2,524,000	1,576,000		
Jan. 15, 4.00 P. M.		42.	2,500	110	95.6	Liquefying and gaseous germs quite plentiful in unfiltered sample, wholly absent in filtered.	2,588,000	3,620,000	1,712,000		
Jan. 22, 3.00 P. M.	Jan. 23.	33.	1,950	90	95.4	Numerous gas-producing bacteria in unfiltered sample, none in filtered.	2,728,000	3,376,000	1,544,000		
Jan. 29, 2.00 P. M.		35.	1,680	540	67.2	Filtered sample free from gaseous germs, unfiltered having the usual number.	2,524,000	4,134,000	2,272,000	Jan. 27	No 1.
Feb. 5, 3.00 P. M.		39.	4,450	445	90.	No gas-producing germs present in filtered sample, although plentiful in unfiltered.	2,300,000	2,664,000	1,516,000		
Feb. 19, 2.30 P. M.	Feb. 20.	45.	480	50	88.9	No gas-producing germs present in filtered sample, although unfiltered contains them in copious quantities.	2,300,000	2,580,000	1,600,000		

operation of the filter in February, 1896. For this purpose Prof. H. L. Russell of the Wisconsin University, at Madison, was selected by Dr. Perkins to direct the taking of samples and to make the analyses thereof. And while for the reasons and causes stated the apparent biological results of filtration shown from these analyses are not to be considered indicative of the true value or practical efficiency of the filter, even during the first year's operation, — and much less for the future when its normal condition and regulation shall have become fully established and provided, — nevertheless, the results of the analyses made for the first year are given herewith for what they may be worth, tabulated in four subdivisions made according to the varying conditions existing throughout different portions of the year.

While authorities differ as to the value to be ascribed to bacterial analyses of raw and filtered water as bases for demonstrating the hygienic value or efficiency of filtration, the evidence afforded in actual mortuary statistics during a long term of years seems to merit and to receive general acceptance as a reliable indication of the practical worth of filtration. The true value of such statistics is found only in their broad general application. Limited to single and especially to small communities, where as at Ashland discrepancies and lack of uniformity in the identification and designation of diseases exists, and where the records cover a comparatively brief period at the best, during one year only of which filtration has been practised, they can have only a remote or, at the best, a cumulative value, yet such indications as they afford in the case of Ashland are in the desired direction, *i. e.*, in support of the assumption that sand filtration, even in the incompleteness of its first year, has had a favorable effect upon the public health, especially in its bearing upon such diseases as are to some extent at least promoted by or communicated through sources of water supply, as may be seen from the following table: —

CITY OF ASHLAND, WIS.

Summary of statistics of deaths for five years from March 1, 1892, to March 1, 1897, compiled from physicians' certificates of causes of deaths, filed with the health officer of Ashland.

Statistics of December, 1892, and March, 1893, are missing from the records, and therefore are not included in this summary.

Year.	Certified causes of deaths				Remarks.
	Typhoid Fever.	Winter Cholera, Summer Complaint, Bowel Complaint, Diarrhœal Diseases, Dysentery, Inflammation of the Bowels.	Other causes, specified and unspecified.	Total.	
March, 1892, to February, 1893..	11	4	163	178	December not included. Records missing.
March, 1893, to February, 1894..	32	17	216	265	March not included. Records missing.
March, 1894, to February, 1895..	40	15	171	226	
March, 1895, to February, 1896..	11	10	196	217	Filtration of water began and all use of raw water discontinued Feb. 8, 1896.
March, 1896, to February, 1897..	7	6	162	175	

DISCUSSION.

Mr. Hazen. I think the thanks of the Association, and of every one who is interested in covered filters or covered reservoirs, are due to Mr. Wheeler for showing us this vaulting. It has been my privilege to examine covered reservoirs and covered filters in a great many cities. There are, as you know, many different systems of vaulting. The older vaultings had lintel arches with a higher row of covering arches sprung from them in another direction. This style of construction was easily built, and was commonly used. It required a rather large amount of masonry, and was not well adapted to filters, because it cut off the head-room in one direction, or else necessitated carrying the side walls and the vaulting up a good deal

higher than would otherwise be necessary. Then the French perfected a system of groined arches with extraordinarily thin masonry, which was, however, somewhat difficult to place and keep in order, so that an American engineer once said that it represented the minimum of material and the maximum of expense. Then there are other filters and reservoirs covered with thicker groined arches. I have a book describing the vaultings used in the Roman reservoirs in Constantinople. Some have very elaborate and most wonderful carving in the vaulting and support; one can hardly understand why such work was put into reservoirs. This style of vaulting requires a great deal of masonry, and, aside from the carving, is necessarily rather expensive. The groined arch work in the newer German reservoirs often has ribs, something like those in Gothic churches. These ribs are apparently regarded as necessary, either to help them in construction, or to take up the extra strain at the corners.

Mr. Wheeler has shown us a vaulting which is free from all this extra masonry, plain and simple, as you have seen from his splendid photographs, and which has proved entirely stable and satisfactory, and he deserves our thanks for showing us how it can be done.

Mr. KNOWLES. I would like to ask Mr. Wheeler if he can tell us something about the cost of running the filter. I did n't hear him say anything about the cost of washing the sand, and I would like to have him tell us about that and how it is done.

Mr. WHEELER. No sand washing is done at Ashland. The sand is delivered on the dock at a price that, without trial, we have supposed to be as low, or probably lower than, we could wash old sand for. The price of the new sand which was used last September for replenishing two compartments was ninety cents per cubic yard, for the sand delivered through the manholes on to the bed, but not distributed, placed. The preceding year the sand cost us sixty-five cents per cubic yard delivered on our land, ready to be barrowed to the manholes and deposited on the bed; hence we have had no occasion to wash any sand.

Mr. COFFIN. I understood Mr. Wheeler to say that the Holly system was used, from which I suppose the pumping is at the ratio of the consumption.

Mr. WHEELER. Yes, sir.

Mr. COFFIN. I have begun some slight studies on the distribution of draught, and of course we all know it is quite varying. I find in

several cases that it runs as high, at certain hours of the day, as 210 or 212 per cent of the average for the day, and in some cases over 300 per cent of the average for the year. Of course, I don't know how that would apply to this plant, but I would like to ask Mr. Wheeler if he has given any attention to that matter in connection with his filters, and at what time in the day the samples were taken for analysis, and if that would not be likely to reduce the efficiency, or apparently reduce the efficiency, of the filters, if the samples were taken, say, along about eight or nine o'clock in the forenoon.

Mr. WHEELER. There is no doubt, Mr. President, that the efficiency of the filters during the past year, as appears in these tables, is very much less by reason of the irregular rate of filtration, that rate being practically the varying rate at which the water is used in the city, the range of which I have no doubt is sometimes as great as Mr. Coffin has found in other cases. The provision, to which I alluded, for regulating the rate of filtration, which is now in construction, will not only regulate the inflow, equalize the filtration in each compartment, but in case of excessive draught will provide for the opening of a connection from the ground water well, so that excessive draught will be supplied from that source, as we have in store some 300,000 gallons above the level at which the water usually stands in the filtered water pump well. The highest rate of filtration, or the ranges of the rate of filtration, which I am now able to give you, are simply the maximum and minimum daily pumpage, which, so far as I have been able to learn from the pumping station record book, which I have now at my office, has been from 1,100,000 gallons per day to about 2,150,000 gallons per day as the maximum. That maximum was upon the day of a very hot fire, the burning of one of the large lumber yards and docks, of which there are several in Ashland.

TESTING WATER PIPE DISTRIBUTION SYSTEMS.

BY F. L. FULLER, C. E., BOSTON, MASS.

[*Read Feb.* 10, 1897.]

Specifications for cast iron water pipe generally call for the application of a pressure of 300 lbs. per square inch at the foundry, in order that any imperfections may be detected. This in connection with the hammer test is likely to show the presence of any cracks or sand holes. If these requirements are complied with, it is reasonably certain that when the pipe leaves the foundry it is free from these defects.

Pipe is, however, very often cracked in transportation. This is especially the case when delivered by rail. During the hurry of switching, with its sudden starting and stopping, pipes often strike each other with considerable violence, and cracks, especially at the spigot ends, are likely to result.

The cracks in some of these pipes may be detected at the time of unloading from the cars, but in many cases they are so fine as to be difficult of discovery. The pipes are liable to still further injury while being hauled from the cars to the street where they are to be laid, and even while lying upon the street until they can be put in the ground. In new works, especially if the pipe is delivered in the winter, considerable time may elapse between delivery on the ground and laying. It is therefore possible, that with the greatest care and the closest inspection, some cracked pipe may be laid.

Of course, when possible, the water should be let on and the pipes flushed and tested before the backfilling is done. As a general thing this can only be done in cases of short extensions, where the work is done by the town or city by days' labor, or where the pipe is not laid in the highway. A contractor is naturally anxious to complete both the pipe laying and backfilling upon a given street before moving his men to another. It is also usually desirable to interfere with the use of the street for public travel for as short a time as possible.

On account of the time required to properly flush and test the pipes, and also on account of the fact that in the case of a new

system, the pumping machinery and reservoir are generally the last things to be completed, it follows that this testing is usually done after the works are practically finished.

When the water is let on to the system, if the pressure is considerable, some of the damaged pipes may be split open, or the cracks opened sufficiently to discharge water enough to appear at the surface. This is also true of imperfectly made joints. Still there are many leaks which do not appear at the top of the ground. This may be because they are small and do not saturate the soil to the surface, or because they are in pipes laid through loose, porous material which allows the water to drain off easily. Leaks or imperfect joints may occur in trenches in rock cuttings which have been partially refilled with broken stone, or near brook or river crossings or culverts.

Under such conditions leaks may exist for years unnoticed, unless some method is employed to thoroughly test the pipes after they are laid in the ground. The amount of water which is lost in 24 hours, through even a small leak is surprising, and may account for the large amount of water pumped and supposed to be used by some towns. A stream so small that it is on the point of turning into separate drops, as obtained at an ordinary faucet, amounts to 25 gallons in 24 hours, or over 9,000 gallons in a year. One hundred such leaks amount to over 912,000 gallons in one year. Most leaks would be much larger than the above, and in a system which had not been tested, the number might be greater.

In order to easily test a system of water pipes, a sufficient number of gates must have been put in, to allow the pipe to be shut off in small sections. It is of course easier to locate a leak within small limits than within large ones. Local conditions will have something to do with the frequency of the gates, but it is well not to be obliged to shut off more than 1,500 feet at a time. When there are many intersections, caused by numerous streets crossing each other, the length of pipe in a section would be likely to be less. It is well to test a pipe system after as many services as possible have been put in, but before the water has come to be much used. By shutting the stop and waste cock on the inside of the cellar wall, the service pipes, including the corporation cock and the flexible lead connection and its joints, are tested, as well as the street mains.

One of the easiest ways of getting an approximate idea of the tightness of a section, is to attach a pressure gauge to a hydrant and

TESTING PUMP ATTACHED TO HYDRANT.

shut the gates which inclose it; also all the stop and waste cocks within the section.

If there are no leaks, or but very small ones, the pressure will fall slowly, or scarcely at all. There may be cracked pipe, or perhaps poor joints, but the static pressure from reservoir or stand pipe may not be sufficient to cause such leakage. Still a cracked pipe should not be allowed in a pipe system, even if it does not leak at the time, for the crack is liable at any time to become larger and make trouble. The flow into the section through a gate which is not tight may make good the loss of water from a small leak, and the pressure be kept up. It might also happen that another gate might allow the passage of water out of the section into another where the pressure was less. The shutting of additional gates might remove some of the uncertainty caused by these defects. It does not require a great deal of time to go over a pipe system of moderate size in this way, and it gives some idea of where leaks may be expected.

The next step should be the use of a hand testing pump connected by a flexible rubber steam hose to one nozzle of a hydrant. To the second nozzle should be attached a pressure gauge. The pump should be mounted on a plank and have a rubber section hose which can be connected to a barrel or tub. The pump referred to, with the necessary fittings, costs about $30. It has a piston one and a half inches in diameter and has a stroke of about six inches. At the ordinary speed of working, the pump would throw about three gallons per minute. This is practically a boiler testing pump, and a pressure of two hundred to three hundred pounds per square inch can easily be obtained, provided the section being tested is tight. The pump has a check valve on both suction and discharge sides, and an additional check valve can be placed in the suction hose near the barrel. There should also be a globe valve on the discharge hose near the hydrant, which can be closed when the pressure has been raised to the desired amount, in order to see whether this pressure can be maintained.

The barrel holding the water to be pumped into the section should have a scale or graduation on the inside, so that the number of gallons pumped per minute can be ascertained.

It is necessary to observe at least two precautions. First, the pipes being tested should be entirely filled with water. If there are pockets of air at any of the summits, the air will be compressed and

act as a cushion, and the desired pressure will not be obtained. The pressure gauge will not be apt to drop back when the pump is stopped, which may give a clew to the trouble.

Second, the drip of the hydrant to which the pump and gauge are connected must close tightly, so that there is no leakage. Sometimes when the desired results cannot be obtained at a certain hydrant, it may be well to change to another where the drip may close better.

It requires three men to do the testing, and if the water to be pumped has to be brought far, a fourth man will be found advantageous. Careful notes should be kept of the results obtained at each section.

If after properly shutting off the section, the pressure can be raised to two hundred or two hundred and fifty pounds, and on shutting the globe valve on the discharge, remains so for ten minutes or more, it may be concluded that the section is tight and the apparatus moved to another section and the operation repeated.

If by continuous pumping the pressure cannot be raised, it is evident that a leak exists.

The amount of water it is necessary to pump into the section per minute to maintain the normal static pressure shows the amount of water that is ordinarily running to waste from that section. If a fair amount of pressure can be maintained by the pump, it shows that the leak is not a large one at that time. Just what is the cause of it can only be guessed.

If, on applying the pump to a closed section, the pressure is low and the full capacity of the pump does not increase the pressure, it is evident that a considerable leak exists, and that it amounts to more than three gallons per minute.

After having been over the entire system with the hand pump, recourse should be had to a piston steam fire engine, if it can be obtained. If it cannot, a steam pump of about 150 gallons a minute capacity, and capable of exerting a pressure of 200 to 300 pounds per square inch, will answer the purpose. A No. 7 boiler feed or pressure pump having a ten-inch steam cylinder, a six-inch water cylinder and twelve-inch stroke with a capacity at 100 strokes per minute of 150 gallons, will be found convenient.

A boiler capable of furnishing steam at 100 pounds pressure will be necessary to run the pump.

Either the steam fire engine or the steam pump should be applied

to all doubtful sections. This can be done by placing the steamer or steam pump within fifty feet of a hydrant located outside of the section to be tested. This hydrant will be under reservoir or standpipe pressure. One length of hose will furnish water to the suction of the steamer or pump. Another line of hose will connect the steamer or pump with an open hydrant within the section to be tested. This latter line of hose must, of course, be strong enough to stand the desired pressure to be put upon the pipe. The pressure should be applied gradually and carefully. By this means enough water can be forced into the section to break any cracked pipe, or force water enough through a poor joint to appear at the surface. It usually takes but a few minutes to show the cause of the leak. After it has been repaired, the testing with the hand pump should be repeated.

In this way it is possible to be quite certain that a pipe system is practically tight. If possible, a pipe system should be thoroughly tested every three or four years.

When pipes are to be laid in deep trenches or cuttings or under railroads or streams where they will be difficult of access in case of leaks, it is a great advantage to test these pipes just before they are laid. By bolting on a proper head or cap at each end and filling with water, and connecting the pump with one of the heads, the pipe can easily be tested to any desired pressure.

The writer has tested a number of pipe systems in the manner described, with very satisfactory results.

[Mr. Fuller then showed the pump and connection as used, and explained their operation.]

DISCUSSION.

Mr. HYDE. I would like to ask how that would work with leaky gates.

Mr. FULLER. Leaky gates are troublesome things. I wish that we could have gates that did not leak. One remedy is to shut off surrounding gates so as to get the advantage of two gates in place of one.

Mr. WALKER. I would like to ask Mr. Fuller whether, in case he had a pipe, the spigot end of which was cracked for three and one half inches and the bell was four inches deep, whether he would throw it out or put it in.

Mr. FULLER. I should think, if the crack at the spigot end came

within the bell, there would not be much trouble from it. I suppose the safer way would be to cut it off. I should say that would be the better way to do and get rid of the crack.

Mr. WALKER. We have laid a great many pipes that were cracked three and a half inches, and the bell four inches deep, and there has been no trouble for two or three months, when all at once there would be a great leak and we would find the crack covered up by tar, notwithstanding it had lasted all that time.

Mr. SMITH. I would like to ask Mr. Fuller if he thinks this method of testing has any advantage over using two meters. The way I test, when I have reason to believe I have trouble, is to attach a meter at the inlet and another at the outlet in any section and throw the water through the section, and if the meters register alike I consider the section tight. If I get a less flow from the outlet than from the inlet, I look for trouble in the section.

Mr. FULLER. Certainly Mr. Smith's method would be economical, but it seems to me that I should be a little better satisfied when I got through with this method than I should with his. If the gang of men are well organized they can go over the ground very quickly.

Mr. CRANDALL. I do not see the object in the use of the second meter.

Mr. SMITH. If you have air pockets, your first meter will show a leak when no leak exists.

Mr. HYDE. The way we test our mains in Newton is to go around in the night, after 12 o'clock, perhaps, and shut off a section by closing the gates. We leave all those gates closed, perhaps fifteen or twenty minutes, then we open one gate through which the supply comes, and if there is a leak in that section you can hear the water going through that under the valve very plainly. If we find that there is a leak in that section we test all the service pipes, and as a general thing we find a leak in one or more of them, and perhaps a leak on the main, but ordinarily we find it without going all around. We find a little leak here and a little leak there, and after going around we find that most of that leakage comes from a leaky ball-cock, but we get a very correct idea of the leakage on our system in that way, which is very simple.

Mr. FULLER. I would like to ask Mr. Hyde how much of the water pumped could be accounted for in the consumption as registered by meters.

Mr. HYDE. I do not think we could get at that very closely; but if we find a leakage on a certain service pipe, by going to that house the next morning, if we find that they have a leaky ball-cock, we know that a certain amount has been wasted, and in that way we find all the leaks in that section.

Mr. STACY. It looks to me as if the whole of this business is guess work. There are many things entering into this testing, and, unless it is very carefully done, and under the right conditions, the result is rather indefinite. That is, it is hard to decide whether it is a leak out of the pipe, or a leak in the gate, or a leak through the service pipe, or where it is. Now, we have never tested any of our pipes. Whenever we have had a leak that showed, of course we have fixed it. We have not had a general leak for something over a year. We have not averaged one a year that has come to our knowledge since the works were built. The one that we did fix about two years ago on Main Street, when we came to it, was about the size of a knitting needle. That showed at the surface, but if it had been in more porous ground it would not have shown at the surface. The hardest leaks that I have to discover have been those in the centre of the pipe. I had two or three of a 16-inch main, carrying a 160-pounds pressure. We found one of them almost by accident. It was just being run on to the skids into the trench. It happened in that carload of pipes that there were two others cracked in the middle, it being caused by dropping, I suppose, in transportation.

Mr. COGGESHALL. I think Mr. Stacey is right on that matter of gates, — that you do not get them always tight the first time. In New Bedford, as Mr. Wood described at the last meeting, we have recently laid a 36-inch cast iron main some five miles in length from the new distributing reservoir to the centre of the city. This was laid by contract, and after it was completed last fall, and the reservoir also completed, it was decided to fill the reservoir, and the only way to do that was to pump back from the old pumping station, raising the water into this reservoir. The pumps at the present pumping station pump under a head of about 45 pounds pressure, and it was necessary to pump under a 75-pound pressure to raise the water into this reservoir. That we did by putting a little extra strain on, and pumped 68,000,000 gallons into that reservoir in thirty-one days, working night and day continuously. Then I thought it would be a good plan to see how tight it was, whether there were any leaks

on our distributing main; so we shut the sluice gate at the reservoir, and made sure that it was perfectly tight by entirely emptying the gate-house. Then we allowed the gate-house to fill up to the same level as the water in the reservoir and closed the gates, and also closed all connections with the present distributing system. In about two days' time the water had fallen in the gate-house less than two feet which indicated that there was a slight leak somewhere. Then we went down to the city end, where there were three gates connecting with the present distributing system, and opened those gates and closed them several times, and then we went up the pipe line about two thousand feet and closed a single gate, and that gate remains closed, and since then the water in the gate-house has kept its level perfectly, showing that there is scarcely any leak on that part of the pipe.

SERVICE GATE BOXES.

BY GEO. A. STACEY, SUPERINTENDENT, MARLBORO, MASS.

[*Read Feb.* 10, 1897.]

GENTLEMEN: I have had a little experience with service gate boxes, some of which has not been altogether satisfactory. Knowing that frost does not have the same effect in all localities I will state that the subsoil of Marlboro is largely clay and gravel hard-pan in which the clay predominates. This expands or heaves in the winter to a considerable extent, and in the spring when the ground begins to thaw out, it leaves the gate boxes from one to two and a half inches above the sidewalk. As this forms an obstruction they must be put down. Sometimes they can be driven down, but often the frost is not all out and an attempt to drive them results in the destruction of the top of the box. In this case, to save the box, I pump in hot water, and by this means succeed in getting them down without damage. The lifting of the box also lifts the base from the pipe and allows dirt and stones to get around the stop, so that after a time, in many cases, you cannot get the key on to the cock, or if you do succeed in that, you cannot shut it off. This is not very pleasant when the stop and waste in the building or the pipe back of it has burst and the water is flowing under from forty to one hundred pounds pressure into a cellar. The only remedy is to try and stop or retard the flow by a wooden plug or a clamp (at the same time getting a shower bath of not always warm water), then dig it up and reset the box.

Another source of trouble is that we find the covers off and broken by the carelessness of some plumber, or by a coal or other heavy team backing on to it, or by a small boy who uses it for a hub to play duck or pitch quoits to, and when he finds a box open, to help matters along, he proceeds to fill it with stones, and he usually finds one just about a fit. To get them out you must dig it up.

This is a small matter, taking the works as a whole, but it is one of the many little things that help make a superintendent's life miserable at times. Perhaps other works do not have much trouble

from this source, or use a box that obviates it. I do not think the boxes we have been using are the ones best adapted to our conditions. My idea of a box is one with the base of the lower section fitting closely to the pipe and stop, with a rather large flange to resist an upward pull and with the top section long enough to reach well down to or below the frost line. The inside diameter should be three quarters of an inch larger than the outside of the lower section, with three or four thin ribs or feathers on the inside, of such a diameter as to slide freely on the lower section, and with a strong flange on the top, with the cover recessed into it. I think this would be a cure for most of the trouble, except the plumber and the small boy, and I do not know of any remedy for them, except that a law be passed exporting the first and to curtail the propagation of the second.

EXPERIENCE PAPER.

BY CHARLES K. WALKER, SUPERINTENDENT, MANCHESTER, N. H.

[*Read Feb.* 10, 1897.]

My experience the past year has not been very pleasant. The trouble began in March, when high water carried off a bridge and the pipe which was laid on it, and which supplied the west side with water. About a thousand feet below this bridge there was a 12-inch pipe which had been laid across on the bed of the river and which was only used when repairs were being made on the line across the bridge. We turned the water on from this 12-inch pipe as soon as we could, but it took some time to find the gate, which was eight feet under water. It was quite a trick to find this gate and get the wrench on. You can imagine how I felt with the water shut off from 10,000 inhabitants and 165 hydrants. The newspapers came out the next day and said that we were lucky to have a pipe in the river as a reserve, but that the gate had been placed too low. I had found this out the day before. It takes a reporter to find out our mistakes after we have found them out ourselves.

I have been Superintendent of the Manchester Water Works for twenty-two years. When I first took charge there were twenty-three miles of pipe, which have since been increased to eighty-seven. We have used five different kinds of hydrants and five different kinds of gates and nearly every kind of meter. I would not recommend any of them; they will all go back on you sometimes. They are like a farmer's mowing machine; if they work well and cause no trouble, we are satisfied.

Meter rates you can never raise, so don't start with them too low. If it so happens that you have too much surplus you can reduce the rates, which is just, and the only right way; but as a rule you will need it. We have one way of doing business which works well: we take the money at the water office and deposit it in the hands of the City Treasurer, and he pays the bills. If there is anything that I would give you advice about without charge it is this: if you are lucky enough to have a surplus, look out and spend it for pipe, supplies, or

something else, for if there is any way that the city can get hold of it, they will use it for streets and sewers, or something besides water works. About five years ago we credited to the Manchester Water Works about $60,000. By some means they got the bars down and gobbled it up. You never can get the money back that is taken that way.

Another matter I will just mention. When the city of Manchester sells its water bonds, the city takes the premium which they bring and uses the money for other purposes and give us no credit. This is unfair.

Many of our service pipes were put in twenty years ago, and are filling up with rust. Cement-lined pipes laid before this time rust from the outside and are giving out. Tarred, enamel and rubber coated pipe are going to pieces. When the lead-lined pipe was first made, about six years ago, I began to use it, and am using it now. We lay inch pipe and run it to the street line.

We have had more trouble with fish getting into the connections than usual. We went fishing every day for about a month last summer. They go through the screens when quite small and grow in the distribution pipes. Nothing but the Lawrence filter would do them up.

I would say something about insurance companies if I dared to, but you know I got pounced on when I spoke of them once before. They want a big connection when they put sprinklers in the shops or mills and say that the water mains are too small. When I see a young man with a pencil behind his ear and a pressure gauge, trying hydrants in a mill yard, I know there is trouble ahead. By the way, did you ever know of a mill or shop stealing water from pipes put in for fire purposes only?

DISCUSSION.

Mr. CRANDALL. There is a six-inch meter in Burlington on one of our fire pipes, and I should judge that a great many people are inquiring as to the propriety of its present use. Whether the same thing is done in other cities and towns, I do not know.

Mr. STACEY. We do not have any meters on ours. It is right to have them on. I understand all about that, but we don't have them. My experience is that when you have a connection with a mill, they will beat you, if you do not have a meter; but if you make a man

who wants a plug pay for everything that goes through the meter, it is all right.

Mr. ROBERTS. In Fall River we do not put any meters on fire pipes on account of the objection of the insurance people. I think that that is the principal reason. We do not have any pipes for fire purposes only. A six-inch pipe is usually the size that we run in for mill protection, and we have no meters on such pipes, but we do meter the taps from such pipes supplying water for other purposes. I would like to know how it is in other cities.

Mr. CRANDALL. Some years ago I wrote to a number of parties on this matter. Mr. Kieran of Fall River was one of them, and I know that there were a number of places where pipes used for fire purposes only were being used for other purposes without paying the city therefor, and they did, in Philadelphia and other places, place meters upon pipes in order to prevent their use for other than fire purposes. In Burlington we have a fire service independent of any other purpose. If a party wishes a fire service he may have it free of charge, but he has no right to have the fire service for other purpose. If you allow a fire service to be used for other purposes, it is utterly impossible to tell how much water is used from it for other purposes.

AN INEXPENSIVE METHOD OF DETERMINING CHARGES FOR PUBLIC USE OF LARGE STREAMS, IN A MEASURE PROPORTIONATE TO THE AMOUNT OF WATER USED.

BY F. H. CRANDALL, C. E., SUPERINTENDENT, BURLINGTON, VT.

[*Read Feb.* 16, 1897.]

Where, in municipalities owning their water plant, the desirability of keeping the accounts of the different departments of public expenditure in such manner as to show the financial standing of each department with approximate accuracy is appreciated, it is often a matter of considerable difficulty to determine what is a fair valuation of the services rendered by the water department in furnishing water for various public uses.

The added force, which the cost of metering the services used for public purposes lends to the idea of the inutility of "transfers made from one pocket to another," as inter-departmental charges are sometimes called, tends to distract attention from the fact that the best means attainable should be taken to prevent the waste of the city's property, whether of water or other commodity.

The fact that the only way to interest the general public in the economical use of water is by making the matter one of personal, pecuniary interest is as true in the case of use for public as for private purposes.

So long as a lack of economy, not to say wasteful extravagance, on the part of an individual, or class of individuals, may take place without expense to them, there is no reason to expect them to practise economy, neither is there any reason to expect the average meter rate payer witnessing the extravagance of such a class to understand how the water which is of so little value that it is allowed to ruh constantly to waste from fixtures in schoolhouses, from park fountains, and from street sprinkling standpipes, can develop such value as it does when it runs for a short time to waste through his meter.

In the search for a method of determining inter-departmental charges for water, particularly those for water used for street sprink-

ling, which should be in a measure proportionate to the water used, and thus afford an incentive to the user to prevent waste, and at the same time avoid the expense of numerous large meters, we have, in Burlington, made some experiments in measuring a part only of the consumption.

It was thought that by the use of a small meter placed in a by-pass around a short contraction of the main line, for approximately the same use under approximately constant pressure, a nearly constant proportion of the consumption could be measured.

Our experiments have been duplicated under both seventy-five and one hundred and twenty pounds pressure and we have thus far been able to measure with a one-half inch meter placed in a by-pass around a short one and one half-inch reduction of a two-inch line within a fraction of one per cent of a constant proportion of the water used on streams from full capacity to one half inch in diameter.

Below the one-half inch stream the proportion measured grows less until on very small streams it is nothing. A check placed in that portion of the main line around which the by-pass is constructed serves the double purpose of causing a slightly larger proportion of the water used to be registered, and placing upon the party wasting the water the loss in case of small leaks. Further investigation with more carefully prepared appliances will very probably result in the measuring of a more constant proportion of the consumption.

Not the least of the advantages of such an arrangement over full size meter is the possibility of taking out the meter with scarcely any interruption of the supply, with none at all if it be deemed best to place stops on either side of the meter, and the utter impossibility of a failure to lay the dust for an afternoon being charged to the obstruction of the water supply by a meter.

The arrangement may be applied on large services supposed to be used at such infrequent intervals and for such purposes as not to warrant the expense of metering, for the purpose of determining the accuracy of the supposition.

In such cases a swing check with weighted lever handle, adjusted at such angle to the valve that the weight, which, when the valve is shut, causes small streams to take to the by-pass, will, when the valve is opened, be thrown off, is more effective and less objectionable as an obstruction of the water way, than an internally weighted check.

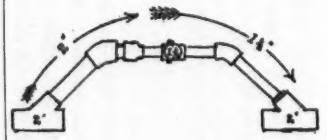
For use on a two-inch sprinkling standpipe an arrangement can be made with a few nipples and standard fittings, a one and one-half inch check and a half-inch meter, costing, exclusive of the meter, about six dollars, which will measure about seven per cent of the flow in streams from full size to one half inch in diameter with not more deviation from accuracy than that of the ordinary one-half inch meter multiplied by the constant used.

On the testing bench the constant factor to be used with the apparatus can readily be ascertained. In setting a meter in such a rigid line the advantage of a long thread and lock nut is apparent.

Whether these results, taking into account the advantages of first cost, cost of maintenance, and non-interruption of supply for care or repairs, the disadvantages resulting from the actual measurement of a part only of the consumption and the particular uses for which it is designed, are satisfactory or no, will be decided differently under different circumstances.

EXPERIMENTS WITH BY-PASSES.

Number.	Meter.	Percentage Metered.						Head lbs.	Check valve.	Description of		
		Full Capacity.		1 inch.	¾ in.	½ in.	Per cent diff'e betw. extremes.			Inlet.	Outlet.	
9	1″ T.	21.5	21.5	21.5	21.25	21.25	.25	75	1½″	3 bushings, smooth bell-shaped orifice.	3 bushings.	
9	1″ T.	21.5	21.5	21.5	21.25	21.25	.25	75	1½″	3 bushings, smooth bell-shaped orifice.	3 bushings.	
9	1″ T.	22	22	21.75	21.75	21.75	.25	120	1½″	3 bushings, smooth bell-shaped orifice.	3 bushings.	
9	½″ N.	8.3	8.2	8.15	8.2	8.3	.15	75	1½″	5 bushings, smooth bell-shaped orifice.	5 bushings.	
9	½″ N.	9.3	9.3	9.2	9.2	9.2	.10	120	1½″	5 bushings, smooth bell-shaped orifice.	5 bushings.	
9	½″ N.	9.4	9.4	9.4	9.4	9.4	0	75	1½″	5 bushings.	5 bushings.	
9	½″ N.	9.5	9.45	9.5	9.5	9.4	.05	120	1½″	5 bushings.	5 bushings.	



RAPHIDOMONAS.

BY GEO. C. WHIPPLE, BIOLOGIST, BOSTON WATER WORKS.

A new organism has appeared to trouble the water works superintendent. Its name is Raphidomonas. It is an infusorian, a minute animal form. Unlike many infusoria it gives trouble not so much by producing a bad taste or odor as in the somewhat novel manner to be described.

The city of Lynn was the seat of the visitation which occurred about the middle of July, 1896. This city uses as its water supply four "ponds" or artificial reservoirs, namely Breeds, Birch, Walden, and Glen Lewis, the first two ordinarily furnishing water of good quality, the last two being at times badly afflicted with growths of micro-organisms. The first three ponds may be used independently or in combination. Glen Lewis Pond can be used only by drawing the water through Walden Pond. Pipe lines connect Birch and Breeds Pond directly with the pumping station. Walden Pond water reaches the pumping station by means of an open canal and a tunnel, leading to the upper end of Birch Pond and thence by a pipe line laid through the pond.

On Sunday, July 12, it was observed by some of the residents living in the western part of the city that the water drawn from the service taps had a decided green color. A glass of it when allowed to stand for even a few minutes showed a heavy green sediment. There was little taste other than that ordinarily present and due to the dissolved organic matter of the swamps. On the following day the water became worse; a thicker layer of "green stuff" was deposited in the tumblers. This caused comment but no alarm. Being Monday, however, the water was used for washing in the laundry and then trouble began. The water left green stains on the clothes, which acted similarly in every respect to grass stains. Boiling intensified them and soap seemed to make them even harder to remove.

A woman living on Hood Street told me about her experience as follows: —

"It was on a Monday. I went out where my daughter was wash-

ing, and as soon as I looked into the tubs I said, 'What makes your clothes look so dingy?' And then she took up a pillow sham which was in a clothes boiler and put it in the rinse and, would you believe it, it was all green like that [pointing to a leaf on a plant in the window]. I was so excited that I did not know what to do, for there was a new white dress in the bottom of the boiler. I pulled it out as soon as I could and found that it was worse than the other. It was green all over. My handkerchiefs were also green and the whole wash was spoiled. I sent one of the handkerchiefs to the Water Board office and the young lady there tried to wash out the green stains but she could n't. They acted just like grass stains. After working over the clothes for a long time and trying chloride of lime and other things I got most of the green out, but the clothes look kind of dingy yet. When I found that it was the water that did it, I boiled it before I used it. That made the green stuff settle worse, but I poured off the top and used that."

During the forenoon complaints began to be made at the central office. They did not come from the whole city, but chiefly from the section known as West Lynn, which is near the pumping station.

At this time water was being drawn from Breeds Pond and Walden Pond. The latter, because of previous offences, was at once suspected, and the water was accordingly shut off and Birch Pond water substituted. The trouble immediately disappeared, and it seemed certain that Walden Pond was guilty. In order to make sure of it, however, Superintendent Haskell caused samples to be collected from all the ponds and sent to the laboratory of the department where microscopical examinations were at once begun. Strangely enough, the samples showed nothing peculiar, even those from Walden Pond. This water contained a few colonies of Volvox globator, and a few green infusoria which in size resembled Phacus and which were so reported. These were the only organisms present which possessed a green color, and which could possibly account for the phenomenon — and their numbers were far too small to cause any trouble.

For this reason it was determined to try Walden Pond water again, but before doing so the writer, in company with the Superintendent, drove to the ponds and made a personal inspection. Samples collected from various parts of Walden Pond, near the dam and from different depths, were found to contain no abnormal growths

of organisms. We then turned our attention to the canal, and it did not take long to become convinced that this was the seat of the trouble. This canal through which all of the Walden Pond water must pass on its way to the city had its sides thickly coated with a growth of filamentous algæ — chiefly Cladophora. The water in the canal was of a dark green color, reminding one of a concentrated pea soup. A bottle of it when held to the light was almost opaque, and was seen to be densely crowded with moving, green particles, which proved to be the infusoria Raphidomonas. These organisms are rich in chlorophyll, and it was this chlorophyll that caused the "grass stains" on the clothes. Samples of the canal water were taken at various points and examined microscopically with the result that each cubic centimeter of water was found to contain from 1,200 to 2,000 Raphidomonas. They were thickest amongst the algæ where they appeared to find a very comfortable home. Doubtless they developed there and gradually scattered themselves out into the water as it passed through the canal. On the day of our visit, Walden Pond was not being used, and as the water in the canal was quiescent, the Raphidomonas had taken possession of everything.

Fortunately, the remedy was a simple one. The water in the canal was wasted through the waste-ways, and the sides and bottoms of the canal were thoroughly cleaned. After a few days, Walden Pond water was turned on again, and no further trouble was experienced. The canal was closely watched for some time thereafter, but no further development of Raphidomonas occurred.

Raphidomonas is not altogether unknown to science, although this is probably the first time that it has ever given trouble in a water supply. Like many other organisms, however, it has passed under a variety of names, each observer as he discovered some hitherto unknown characteristic thinking that this characteristic was sufficient to warrant the creation of a new genus, or else believing that his more accurate description deserved a re-christening. This multiplication of names, while it may be a mark of progress in knowledge, has caused a vast amount of confusion in all branches of natural history. Scientists have almost always taken greater pains to record differences among organisms than they have resemblances. Our Raphidomonas was probably first observed by Ehrenberg in some swamp near Berlin. He describes it under the name of *Monas semen* as follows: —

MONAS SEMEN (*Ehrenberg*).

"Body large, green, obovate, somewhat compressed, dilated and rounded anteriorly, attenuated posteriorly; a triangular cleft of the mouth at the forward end; many vibrating cilia. Length 1/48‴. Slow, vacillating movement. A central subglobose hyaline gland. Many green ovules. A contractile vacuole, and thin rod-like bodies visible. A narrow cleft observed extending from the mouth. Observed in January and February in decayed sphagnum in a swamp near Berlin."

Diesing in his "Revision der Prothelminthen" quotes Ehrenberg's description, adds a few words of his own, rearranges the matter, and changes the name to Gonyostomum. His description is given below. Whether Diesing himself saw the organisms or whether he bases his description wholly on Ehrenberg's account is unknown.

GONYOSTOMUM.

"Animalcules solitary, free swimming, symmetrical. Body obovate, unchangeable, green, not caudate, neither cilia nor lorica. Mouth on ventral surface, triangular, ciliated. No flagellum anus or eyespot. Inhabits fresh water.

"Spontaneous division unknown. Movement slow, vacillating, a central subglobose hyaline gland. Large green ovate bodies. A contractile vacuole and thin rod-like bodies visible. A narrow cleft extending from the mouth." (Ehrenberg.)

G. SEMEN (*Diesing.*)

"Body obovate, somewhat compressed, dilated and rounded anteriorly, attenuated posteriorly. Length 1/48‴. Habitat, in decayed sphagnum moss in a swamp near Berlin, January and February." (Ehrenberg.)

Stein in his magnificent work, published in 1878, gives a number of figures of our organism and these, with the index to the same, may be considered as the most accurate description up to the present time. These figures are shown on Plate No. 1. Stein gave to the organism the new generic name of Raphidomonas, but kept Ehrenberg's specific name semen, writing it thus, "Raphidomonas semen, (Ehr.) Stein." This was strictly in accord with etiquette as he took the generic name "Monas" given by the first observer and added to it a prefix which described one of its important characteristics. Bütschli has preferred to keep Diesing's name Gonyostomum. Later authorities have been somewhat evenly divided between the two. The present writer proposes to adhere to Raphidomonas semen, because of its appropriateness and because of its similarity to the

name given by the first discoverer, even though, as will be shown, Stein's description is faulty in one essential particular.

From Stein we learn that the animalcule is a free-swimming form having an elongate-ovate body, somewhat flexible, usually widest anteriorly, tapering posteriorly, and being generally two and one half to three times as long as wide, the length varying from 44 to 64 microns. The organism is monoflagellate, but a second flagellum has at times been observed. The oral aperture or mouth is placed at the anterior end and conducts into a conspicuous pharyngial chamber, triangular or lunate in shape, placed transversely. The contractile vescicle is conspicuous and anteriorly situated. The ovate nucleus is situated near the centre of the body. In some individuals there is a large "germ sphere" posteriorly located. The animalcule has a beautiful green color due to the presence of numerous large chlorophyll grains evenly distributed over the cuticular layer. Among these there are seen numerous rod-like or nettle-like bodies known as trichocysts, somewhat more numerous along the anterior margin than elsewhere over the surface. The organism moves somewhat sluggishly, but certain skipping movements are referred to.

The organisms seen by the writer are in most respects in accord with Stein's description. There is one very important difference however, namely: *they all have two flagella.* This feature is so constant that there is no doubt that Raphidomonas should be called bi-flagellate and not monoflagellate. Indeed, Stein himself alludes to the occasional presence of a "second flagellum directed backwards." It is perhaps not surprising that Stein should have overlooked the second flagellum because the microscopes of those days were inferior to those now in use, and because the second flagellum, and indeed sometimes both flagella, may easily be broken off by rough handling so that only a stump remains. This accident happened to a number of organisms which the writer recently sent through the mail.

The fact that Raphidomonas is a bi-flagellate infusorian is an important one when considering its place in a scientific classification.

Bütschli includes it (Gonyostomum) in the order Euglenoidea and the family Cœlomonadina, the other members of the family being Cœlomonas, Chromulina, Microglena, and Vacuolaria. In this connection it is interesting to note that Dr. A. C. Stokes has recently described a form which he has named Tentonia, which differs from

Raphidomonas only in the non-possession of trichocysts. It has two sub-equal flagella — one directed forwards and the other trailing.

The writer, not being an expert taxonomist, will not attempt to put Raphidomonas semen in its proper place, but wishes simply to call attention to its bi-flagellate nature.

The two flagella are approximately equal in length both being about half as long as the body of the organism and both issuing from the oral fossa. Both are vibratile, but one of them which is usually projected forwards, moves with a slow, deliberate, waving motion, while the second one, which is often coiled spirally near the body, but which is projected sometimes forward and sometimes backward, moves more rapidly with a coiling and twisting motion. It is probable that the sudden louse-like skipping movements of the organism are due to the rapid motions of this second flagellum.

The body of the organisms observed in the Lynn water were somewhat more obtuse than those figured by Stein. The length varied from fifty to seventy microns, averaging about sixty, and the breadth being generally about forty microns. These measurements were taken when the organisms were at rest. It was observed that when in motion the organisms lengthened out considerably, stretching forward, as it were, and instantly coming back to their normal shape when they stopped. Many abnormal forms were observed reminding one of the various shapes assumed by Euglena viridis. Raphidomonas from one or two other localities have corresponded more closely with the proportions of Stein's specimens.

The pharyngeal chamber has been described as triangular or lunate. This, on the whole, is a good description for the shape of the cavity when the organism is at rest. When in motion it becomes almost spherical. The contractile vesicle and the nucleus are quite conspicuous, the latter often being spherical rather than ovate, as depicted by Stein. The trichocysts, so far as I have observed, are quite uniformly distributed over the surface and are not more numerous at the anterior extremity than elsewhere. They are minute, dark-colored rods measuring five by one-half microns. Normally, they are arranged in a direction parallel to the axis of the organism. Their function is not known.

The chlorophyll grains, which make the organism an important one in the eyes of the sanitary biologist, are crowded closely together over the entire surface, giving to the organism a brilliant green color.

They are irregularly spherical and measure about three microns in diameter. On the breaking up of the organism the chlorophyll grains become scattered. Later, they themselves disintegrate, the chlorophyll becomes diffused, and minute oil globules are visible. The green coloring matter is readily soluble in ether, and, so far as observed, is in every way similar to the chlorophyll of plants.

In regard to the method of reproduction we know comparatively little. Stein speaks of a "germ sphere" as being present near the posterior extremity of some individuals, and Stokes affirms that his allied genus, Trentonia, reproduces by "encystment with subsequent binary fission." In this connection the following observations by the writer may be of interest, as they appear to indicate that reproduction takes place by sporular encystment.

It was frequently observed that if the Raphidomonas were allowed to stand for some time in a closed bottle, some individuals would disintegrate; others would lose some of their chlorophyll granules, and then become very compact, almost sperical in form. At the same time the "germ sphere" of Stein would become visible in the centre of the spherical mass. This would gradually take on a yellowish and then a dark brown color, and at the same time, oil globules would become visible in it. Later the chlorophyll granules would become diffused, other colorless round bodies would appear, and the brown colored matter in the "germ sphere" or sporocyst would collect in well-defined irregular masses. The escape of the sporocyst from the body of the organism and its subsequent rupture were not observed, but in the water were found many brown colored sub-spherical bodies which in size and color resembled the small masses in the sporocysts. These spheres were usually about four microns in diameter. They possessed a double cell wall. Whether they themselves subdivide is unknown, but, at any rate, several groups of smaller spheres were also observed.

Raphidomonas is negatively heliotropic. When allowed to stand in a bottle the organisms invariably move rapidly to that portion of the bottle farthest from the light, and, in seeking for them in a pond, they are usually found most abundantly in some shaded spot.

Raphidomonas has been found in other places besides the canal from Walden Pond. It was present in Walden Pond itself for some time before and after the episode of the green clothes, as will be seen from the following table: —

NUMBER OF STANDARD UNITS * OF RAPHIDOMONAS PER CUBIC CENTIMETER IN WALDEN POND, LYNN, MASS.

	SURFACE.	BOTTOM.
July 6, 1896	8	28
" 14, 1896	14	14
" 20, 1896	48	—
Aug. 3, 1896	24	18
" 10, 1896	42	48
" 17, 1896	120	52

It was also found about the same time in Birch and Breeds ponds, Lynn, but not in Glen Lewis Pond.

Soon after this, Mr. D. D. Jackson, assistant biologist of the Massachusetts State Board of Health wrote me that Raphidomonas was present in one of the Winchester reservoirs. Together we visited the spot and took a number of samples, finding the organisms in every one, but only in small numbers. More recently it has been seen in other surface waters in this State.

It seems more than probable that Raphidomonas is widely distributed in this region and that it is quite common in water supplies taken from ponds and artificial reservoirs. Everything points to the fact that its favorite habitat is the stagnant water of some swamp, where decaying vegetable matter is abundant. Recently in looking over the records of microscopical examinations made at the biological laboratory of the Boston Water Works the writer has been interested to note that Raphidomonas were present in the waters of Cedar Swamp Pond and of Whiteball Pond in the autumn of 1892. They were not abundant enough to make a complete study, and were recorded as "unidentified green infusoria." These same green infusoria, which were without doubt identical with Raphidomonas, have occasionally been seen in other portions of the Boston Water supply. Moreover, it seems probable that the organism has sometimes been recorded as Phacus, which it resembles somewhat in size and color.

In conclusion, the writer desires to express his obligations to Dr. A. C. Stokes, who kindly examined some of the living specimens, and to Mr. Gary N. Calkins, of the Department of Zoölogy of Columbia University, who has reviewed the descriptions and who

* One standard unit equals 400 sq. microns.

endorses the position taken regarding the name, Raphidomonas semen (Ehr.) Stein-Whipple.

LITERATURE.

1. *Ehrenberg, Chr. G.* "Ueber die neuerlich bei Berlin vorgekommenen neuen Formen des mikroskopischen Lebens." Monatsberichte der Berlin Akad, 1853, pp. 189–194.

2. *Diesing, K. M.* "Revision der Prothelminthen." Sitzbungberichte der math. nat. Kl. d. Akad. zu Wien, Bd. LII., 1866, pp. 287–402.

3. *Stein, Dr. Ritter von.* "Der Organismus der Infusionthiere, III., Der Organismus der Flagellaten oder Geisselinfusorien." 1 Halfte. Leipzig, 1878.

4. *Bütschli, Dr. O.* "Klassen und Ordungen des Thier–Reichs." II., Abtheilung, p. 819, Leipsig und Heidelberg, 1883–87.

5. *Kent, W. Saville.* "A Manual of the Infusoria." Vol. I., p. 391, London, 1880–81.

6. *Eyferth, B.* "Die Einfachsten Lebensformen des Thier- und Pflanzenreiches." P. 61, Braunschweig, 1885.

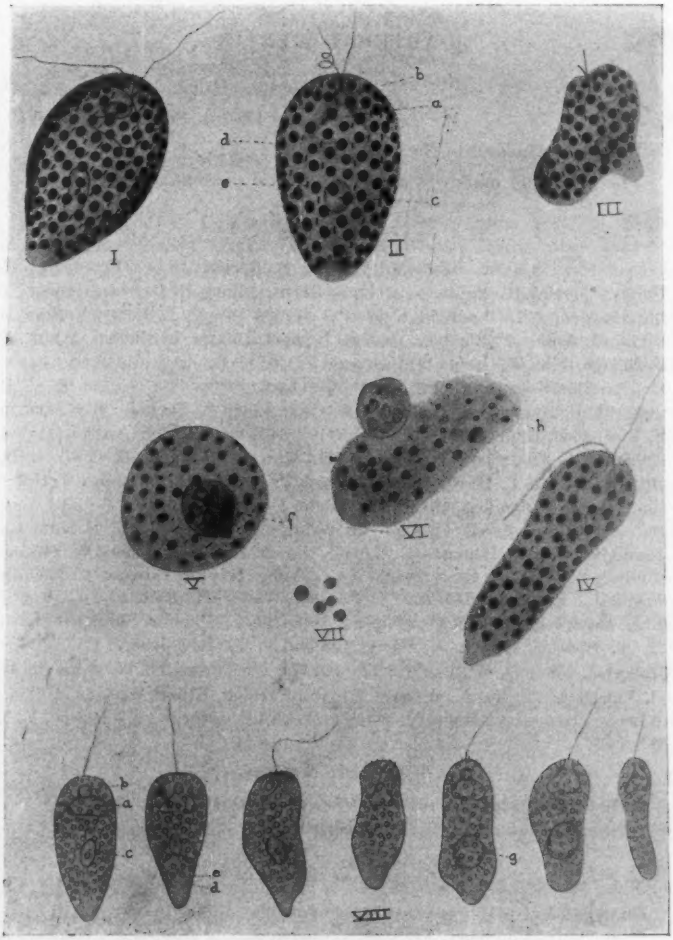
7. *Blochmann, Dr. Friedrich.* "Die Mikroskopische Thierwelt des Susswassers." Theil II., p. 35.

8. *Lancaster, E. R.* "Protozoa" in Enc. Brit.

9. *Stokes, Dr. A. C.* "A Preliminary Contribution towards a History of the Fresh Water Infusoria of the United States." Jour. of the Trenton Nat. His. Soc., Jan., 1888, Vol. 1, No. 3, p. 125.

DISCUSSION.

Mr. JACKSON. In connection with Mr. Whipple's paper, I would like to state I have seen the organism of which he speaks in quite a number of places throughout the State. It seems to be quite widely distributed, but it is more noticeable in Lynn, Walden Pond, and in the middle reservoir at Winchester. The organism must be present in very large numbers to cause green stains in the laundry. Small numbers of all these detrimental organisms occur throughout the State in various water supplies, and give no trouble whatever.



RAPHIDOMONAS.

QUARTERLY MEETING.

YOUNG'S HOTEL,
Boston, March 10, 1897.

President Haskell in the chair.

The following members and guests were present: —

ACTIVE MEMBERS.

Everett L. Abbott, Solon M. Allis, R. S. Bartlett, E. C. Brooks, E. W. Bailey, Charles H. Baldwin, Everett Barns, Albert P. Barrett, George H. Barrus, George E. Batchelder, Oren B. Bates, Joseph E. Beals, Nathan B. Bickford, James F. Bigelow, George Bowers, Dexter Brackett, Arthur W. F. Brown, John T. Cavanaugh, George F. Chace, E. J. Chadbourne, Charles E. Chandler, John C. Chase, Harry W. Clark, Freeman C. Coffin, R. C. P. Coggeshall, Byron I. Cook, Henry A. Cook, Lorin N. Farnum, B. R. Felton, F. F. Forbes, Frank L. Fuller, Julius C. Gilbert, Albert S. Glover, W. J. Goldthwait, Frederick W. Gow, E. H. Gowing, John C. Haskell, L. M. Hastings, Louis E. Hawes, T. G. Hazard, Jr., Allen Hazen, John S. Hodgson, Horace G. Holden, Horatio N. Hyde, Daniel D. Jackson, Willard Kent, Patrick Kieran, Frank C. Kimball, George A. Kimball, Morris Knowles, James W. Locke, Thomas C. Lovell, James L. Lusk, James W. Morse, Charles F. Murphy, H. A. Nash, Jr., Thomas Naylor, Edward C. Nichols, Frank L. Northrop, Horatio N. Parker, Walter H. Richards, George J. Ries, Daniel Russell, F. J. Shepard, Melville A. Sinclair, Solon F. Smith, H. T. Sparks, George A. Stacy, Lucian A. Taylor, Joseph G. Tenney, Robert J. Thomas, William H. Thomas, D. N. Tower, D. W. Tenney, W. H. Vaughan, Charles K. Walker, J. Alferd Welch, Elbert Wheeler, William Wheeler, George C. Whipple, John C. Whitney, George E. Winslow, E. T. Wiswall.

HONORARY MEMBERS.

"The Engineering Record," by C. J. Underwood.
"Fire and Water," by F. W. Shepperd.

ASSOCIATE MEMBERS.

Chapman Valve Manufacturing Company, by E. L. Ross.
Coffin Valve Company, by A. A. Blossom.
Deane Steam Pump Company, by Messrs. Hayes, Pierce & Richardson.
M. J. Drummond, by W. F. Briggs.
George E. Gilchrist, by F. N. Stebbins.
Henry F. Jenks.

Ludlow Valve Manufacturing Company, by H. F. Gould.
National Meter Company, by J. G. Lufkin.
Perrin, Seamans & Co., by H. L. Bond.
Rensselaer Manufacturing Company, by F. S. Bates.
R. A. Robertson.
Anthony P. Smith, by W. H. Van Winkle.
Benjamin C. Smith, by F. A. Smith.
Union Water Meter Company, by J. P. K. Otis.
R. D. Wood & Co., by Jesse Garrett.
The Edward P. Allis Co.

GUESTS.

Peter Milne, Chief Engineer, Brooklyn, N. Y.; F. L. Weaver, Water Commissioner, Lowell, Mass.; L. H. Jones, Water Commissioner, Lowell, Mass.; J. G. DeMello, Foreman, New Bedford, Mass.; J. J. Moore, Boston, Mass.; F. W. Reynolds, Boston, Mass.; Thomas Rogers, Pumping Engineer, Nashua, N. H.; A. W. Barnes, Fitchburg, Mass.; F. Strout, Pumping Engineer, Reading, Mass.; Edwin Kieran, Weymouth, Mass.; Robert Mitchell, Weymouth, Mass.; J. J. Stockton, Bangor, Me.; H. B. Tower, Cohasset, Mass.; Mr. Pratt, Mr. Riley, Mr. McCarty, and Mr. Dwyer of Marlboro, Mass.; Mr. Killam, Brockton, Mass.; Mr. Groce, Dr. Hurlburt Hill, Mr. R. S. Weston.

The Secretary read the names of the following applicants for membership, recommended by the Executive Committee: —

RESIDENT ACTIVE.

George L. Chapin, Commissioner, Lincoln, Mass.
Horatio N. Parker, Assistant Biologist, Western Division, Boston Water Works.

NON-RESIDENT ACTIVE.

Morris Sherrerd, Newark, N. J., Engineer Newark Water Department.
Charles Comstock Hopkins, Rome, N. Y., Stanwix Engineering Co.
Charles W. Knight, Rome, N. Y., Stanwix Engineering Co.

On motion of Mr. Coggeshall, the Secretary was directed to cast the ballot of the association for the candidates, and they were declared elected.

The President announced that the Executive Committee had decided that the June meeting of the association would be made the occasion of a visit to the Metropolitan Water Works at Clinton; and that the annual meeting of the association would be held at Newport, R. I., beginning on the second Wednesday in September.

The President then called upon Mr. Peter Milne of Brooklyn, Sec-

retary of the American Water Works Association, who was received with applause, and spoke as follows:

Mr. MILNE. Mr. Chairman and gentlemen of the New England Water Works Association, I thank you for your kind reception. I am glad to meet you here in a fraternal spirit. I do not feel like trespassing upon the time which is assigned for other and more important work. I can only say that your manifestation of kindness expressed to me to-day, I will take and transmit as the Secretary of the American Water Works Association. I am here in an official capacity for the city of Brooklyn, and I feel as if I were one of this family, that the men here are almost brothers to me, even if I know them not by name. I have been long enough in water works practice to realize the trials and experiences of officials in water works administration. I have noted with great satisfaction the progress and development of the New England Water Works Association, and it is no small degree of honor to you, gentlemen, that you have contributed out of your organization a great deal to the material welfare of the communities which you represent, and have done much to develop water works practice throughout New England and the country. You may well believe and congratulate yourselves that individually and collectively you have in no small degree contributed to promote the efficiency of water works practice. Your literature is sought for and is now deposited in the archives of the most important libraries of the country pertaining to our profession. [*Applause.*]

Mr. William Wheeler, of Boston, presented a paper describing the "Covered Filters at Ashland, Wis."

Mr. Lewis M. Bancroft submitted a paper, which was read by Mr. Hazen, on "The Iron Removal Plant at Reading, Mass."

Mr. George C. Whipple, Biologist of the Boston Water Works, read a paper on "Raphidomonas."

Adjourned.